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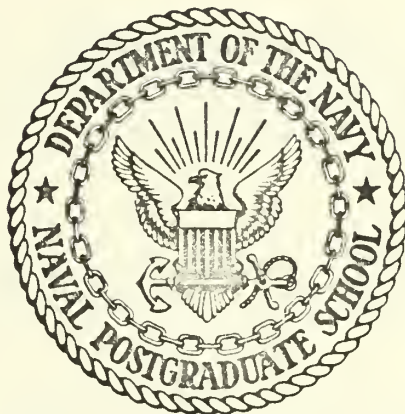
A DIGITAL COMPUTER STUDY OF THE BUCKLING  
OF ACTUAL IMPERFECT CYLINDERS -  
A MODIFICATION  
OF THE COMPUTER PROGRAM SATANS -  
THEORY AND USER'S MANUAL  
FOR SATANS-I AND SATANS II

Bruce Anthony Ryan



# NAVAL POSTGRADUATE SCHOOL

## Monterey, California



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by

Bruce Anthony Ryan

Thesis Advisor:

R. E. BALL

December 1972

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A Digital Computer Study of the Buckling  
of  
Actual Imperfect Cylinders -  
A Modification of the Computer Program SATANS -  
Theory and User's Manual for SATANS-I and SATANS-II

by

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AERONAUTICAL ENGINEER

from the

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ABSTRACT

A digital computer program for the geometrically nonlinear static and dynamic response of arbitrarily loaded shells of revolution known as SATANS is modified, removing a requirement that the applied loads be symmetric about a datum meridional plane. The ability to include arbitrary naturally-occurring initial geometric imperfections of any shape, location or extent is added to the program. Two specific axially loaded circular cylinders are analyzed using actual initial imperfections. Detailed numerical studies are conducted to determine the buckling loads of the perfect and imperfect cylinders. Several sets of boundary conditions are considered. An analysis procedure for imperfect shells is proposed. The results indicate that a means to conduct a numerical analysis of an arbitrarily imperfect shell of revolution has been developed.

A study of the buckling behavior of the clamped shallow spherical cap modelled under various boundary conditions at the pole is included as an addendum.



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#### ADDENDUM

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# TABLE OF SYMBOLS

$a$	= reference length
$b$	= nondimensional inplane stiffness
$E$	= Young's modulus
$E_0$	= reference Young's modulus
$h$	= thickness
$h_0$	= reference thickness
$H$	= rise of a shallow spherical cap
$m$	= harmonic number, meridional
$M_s, M_\theta, M_{s\theta}$	= bending and twisting moments per unit length
$m_s, m_\theta, m_{s\theta}$	= nondimensional bending and twisting moment series coefficients
$n$	= harmonic number, circumferential
$N_s, N_\theta, N_{s\theta}$	= membrane forces per unit length
$p$	= nondimensional pressure load series coefficient
$\hat{Q}_s$	= effective transverse force
$q, q_s, q_\theta$	= normal, meridional and circumferential components of applied pressure loading
$q/q_0$	= ratio of applied load to critical load
$R_s, R_\theta$	= principal radii of curvature
$r$	= normal distance from the axis of the shell
$s$	= meridional shell coordinate
$t_s, t_\theta, t_{s\theta}$	= nondimensional membrane force series
$t_T$	= nondimensional thermal membrane force series coefficient
$U, V$	= displacements tangent to the meridian and tangent to the parallel circle



$u, v$	= nondimensional series coefficients of $U, V$
$W$	= displacement normal to the reference surface
$\bar{W}$	= displacement normal to the reference surface due to initial imperfections
$w$	= nondimensional series coefficient of $W$
$\beta, \beta_s, \beta_\theta, \beta_{s\theta}$	= nondimensional nonlinear term series coefficients in the strain-displacement equations
$\Delta$	= distance between stations
$\epsilon_s, \epsilon_\theta, \epsilon_{s\theta}$	= nondimensional reference surface strain coefficients
$\bar{\epsilon}_s, \bar{\epsilon}_\theta, \bar{\epsilon}_{s\theta}$	= nondimensional reference surface imperfection strain series coefficients
$\zeta$	= shell coordinate perpendicular to the reference surface
$\theta$	= shell circumferential coordinate
$\eta, \eta_s, \eta_\theta, \eta_{s\theta}$	= nondimensional nonlinear term series coefficients in the equilibrium equations
$\lambda$	= nondimensional geometric descriptive parameter for a spherical cap
$\nu$	= Poisson's ratio
$\sigma_0$	= reference stress level
$\rho$	= nondimensional radius
$\omega_s, \omega_\theta$	= nondimensional curvatures
$\Phi, \Phi_s, \Phi_\theta$	= reference surface rotations
$\bar{\Phi}_s, \bar{\Phi}_\theta$	= reference surface rotations due to initial imperfections
$\phi, \phi_s, \phi_\theta$	= nondimensional series coefficients for reference surface rotations
$\bar{\phi}_s, \bar{\phi}_\theta$	= nondimensional series coefficients for reference surface rotations due to initial imperfections
$[ \bar{\Omega} ], [ \bar{\Lambda} ]$	= 4 x 4 boundary condition matrices



$\{l\}$  = 1 x 4 boundary condition matrix

$\underline{\underline{E}}, \underline{\underline{F}}, \underline{\underline{G}}$  = matrices [Refs. 3 and 4]

$\sum_1^{\infty}$  = a summation, on the harmonic index number  $n$ , where  $n = 1, 2, \dots, \infty$

#### SUPERSCRIPTS

- $^1$  = indicates the coefficient of a previously existing term
- $^2$  = indicates the coefficient of a newly introduced term
- $^{12}$  = indicates the coefficient of the product of a previously existing term and a newly introduced term
- $(n)$  = Fourier index
- $'$  = (prime), partial differentiation in the meridional direction
- $\cdot$  = (dot), partial differentiation in the circumferential direction



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## I. INTRODUCTION

Shells are used as structural elements in nearly every space vehicle, aircraft or other structure where light weight is of importance. Consequently, a large number of digital computer programs for the structural analysis of this shells have been developed. Many of these programs were briefly described by Bushnell in Ref. 1. An assessment concerning the analysis capability based on computational systems that have application to a broad class of shell structures was presented by Hartung in Ref. 2. In his assessment, Hartung discusses the limitations, scope, accuracy and efficiency of virtually every major shell structural analysis program currently available and under development. Of particular interest here, is the computer program SATANS -- Static And Transient Analysis, Nonlinear, Shells -- developed by Ball for the geometrically nonlinear analysis of arbitrarily loaded shells of revolution [Refs. 3 and 4].

First, in section II, a brief description of SATANS is presented including the basic theory, the program capabilities and limitations, the solution method and procedure and some general comments.

Second, in section III, SATANS-I is constructed. Modifications to SATANS making the program more user oriented are discussed. Included in these modifications are a reorganization of most of SATANS into a 'storable package,' incorporation of an equipment-independent plotting package



which uses a high-speed line printer, modification of iteration control, discussion of extrapolation technique and alteration of boundary load application procedures.

Third, and most important, the subject of imperfections is treated in section IV. Thin isotropic shells of revolution have consistently displayed experimental buckling loads much lower than the theoretically predicted buckling loads. This disagreement has generally been attributed to (1), the mathematical inability to correctly model the boundary conditions as they exist on the test specimen, and (2), a high degree of imperfection sensitivity, i.e., naturally-occurring imperfections in the initial shape of the shell cause a premature triggering of critical buckling modes and early shell collapse. An attempt by Dantone [Ref. 5] to modify SATANS and to include initial imperfections in the analysis of cylindrical shells was severely hampered by a restriction on the use of SATANS, namely, all applied loading and initial conditions -- and hence, initial imperfections -- must be symmetric about some meridional plane. Discussion of the removal of this restriction and introduction of initial imperfections into the program are covered in this section.

Fourth, and also in section IV, the implementation of the initial imperfection capability is presented. The resulting program is called SATANS-II. Steps for actual construction of SATANS-II from SATANS-I are presented as are instructions for its use.



Fifth, in section V, actual imperfect shell analyses are performed on two specific axially loaded circular cylinders. The actual topography of the cylinders has been measured by Arbocz and Babcock [Ref. 6] and this data provides the opportunity to include actual naturally-occurring initial imperfections into the analysis by SATANS-II. Detailed numerical studies are performed to determine the classical and consistent bifurcation buckling loads of the perfect cylinders and the results are compared with previously published results. Stability solutions for the imperfect cylinders under six boundary conditions are obtained and compared with experimental values. An analysis procedure for imperfect shells is proposed based upon these results.

Lastly, as an addendum to this report, the clamped shallow spherical cap is investigated under various boundary conditions at the pole. While on an industrial tour with the Structural Analysis Division of the Palo Alto Research Laboratory of the Lockheed Missiles and Space Company, Sunnyvale, California, Ryan noted that few shell structural analysis programs have the capability of analyzing a shell of revolution which has an initial or a final pole -- continuous structure through the axis of revolution. This investigation attempted to determine the effects on the solution caused by substitution of a small hole or a small rigid plug for the pole.



## II. DESCRIPTION OF SATANS

The computer program known as SATANS is capable of performing static and transient analyses of thin, linearly-elastic shells of revolution subjected to arbitrary loads and temperature distributions. It is based on Sanders' nonlinear field equations [Ref. 7] for the conditions of small strains and moderately small rotations. The program can be used under the following conditions:

1. The geometric and material properties of the shell must be axisymmetric, but may vary along the shell meridian.
2. The shell material must be isotropic, but the modulus of elasticity may vary through the thickness.
3. Poisson's ratio must be constant.
4. The boundaries of the shell may be closed, fixed, elastically restrained or free, and loaded or unloaded.
5. The applied forces, pressures, temperatures and initial conditions must be symmetric about a datum meridional plane.

### A. GEOMETRY AND COORDINATE SYSTEM

The coordinate system used to locate points within the shell is the  $s, \theta, \zeta$  orthogonal system, where  $s$  is the meridional distance along a reference surface,  $\theta$  is the circumferential angle measured about the axis of revolution and  $\zeta$  is the perpendicular distance from the reference surface. The shell geometry and coordinate system are shown





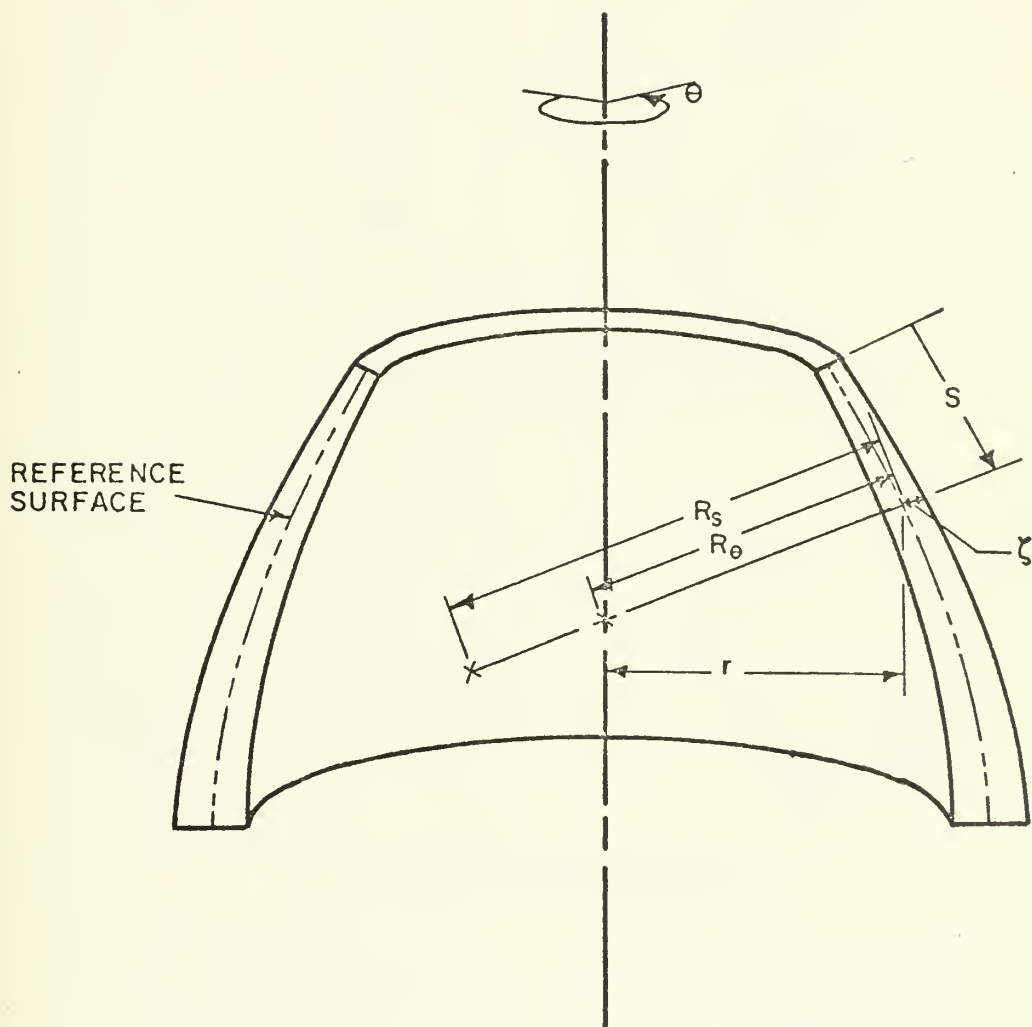
in Figure 1. Positive directions for displacements, rotations, forces, moments and loads are shown in Figure 2.

## B. METHOD OF SOLUTION

The governing partial differential equations are reduced to an infinite number of sets of four second order differential equations in the meridional and time coordinates by expanding all dependent variables in a sine or cosine series in terms of  $n\theta$ , where  $n$  is the Fourier index (harmonic) and  $\theta$  is the circumferential coordinate. The sets are uncoupled by utilizing appropriate trigonometric identities and by treating the nonlinear coupling terms as 'pseudo loads.' The meridional derivatives are replaced by conventional central finite difference approximations, and the displacement accelerations are approximated by the implicit Houbolt backward differencing scheme [Ref. 8]. This leads to sets of algebraic equations in terms of the dependent variables and the Fourier index or harmonic. At each load or time step, an estimate of the solution is obtained by extrapolation from the solutions at previous load or time steps. The sets of algebraic equations are repeatedly solved using Potters' form of Gaussian elimination [Ref. 9]. The pseudo loads are recomputed after each solution and the procedure continues until the solution converges.

In the static analysis, a load-displacement history is obtained by an automatic incrementing of applied loadings in equal steps until the number of iterations required to achieve convergence in any harmonic exceeds a prescribed

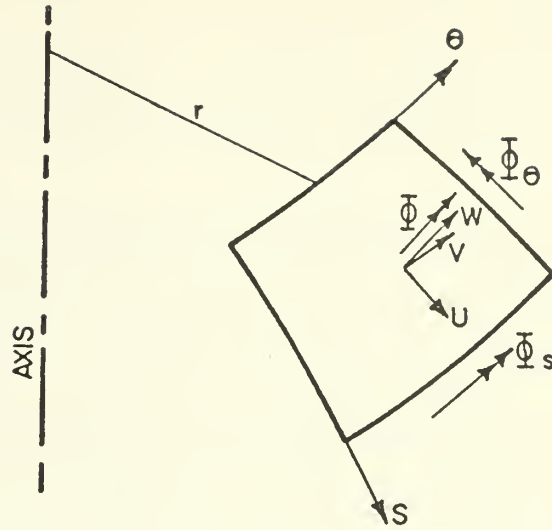




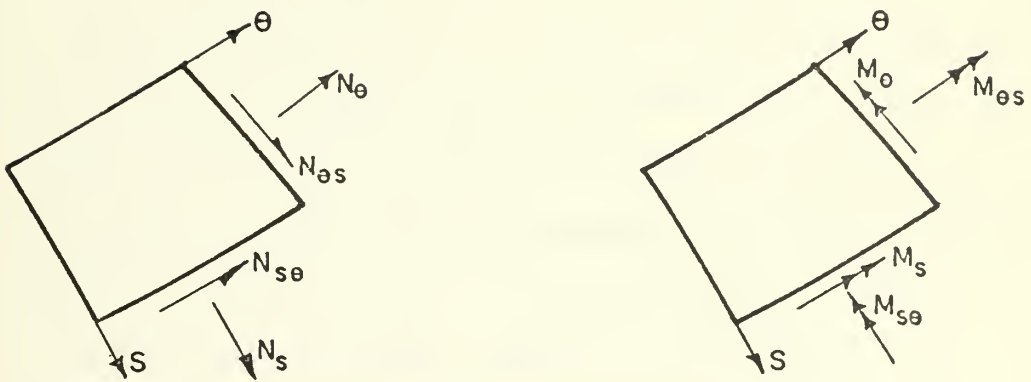
SHELL GEOMETRY AND COORDINATE SYSTEM

FIGURE 1

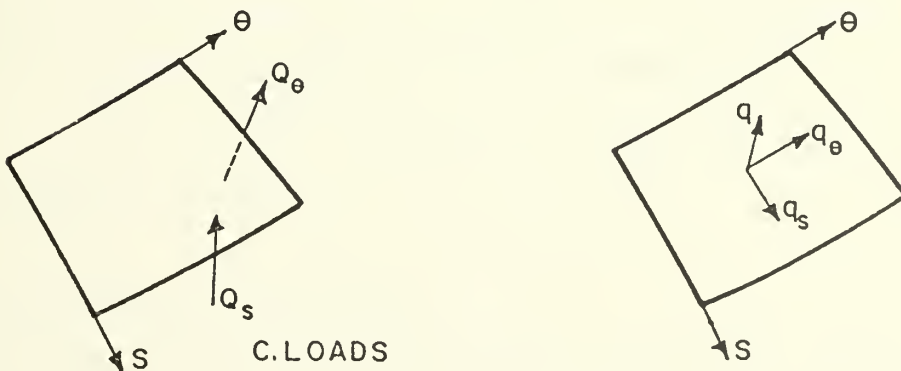




A. DISPLACEMENTS AND ROTATIONS



B. FORCES AND MOMENTS



C. LOADS

POSITIVE DIRECTIONS FOR VARIABLES

FIGURE 2



limit. The load increment is then reduced by a factor of five and the procedure continues until a prescribed number of load steps, or a prescribed number of load step reductions have been made.

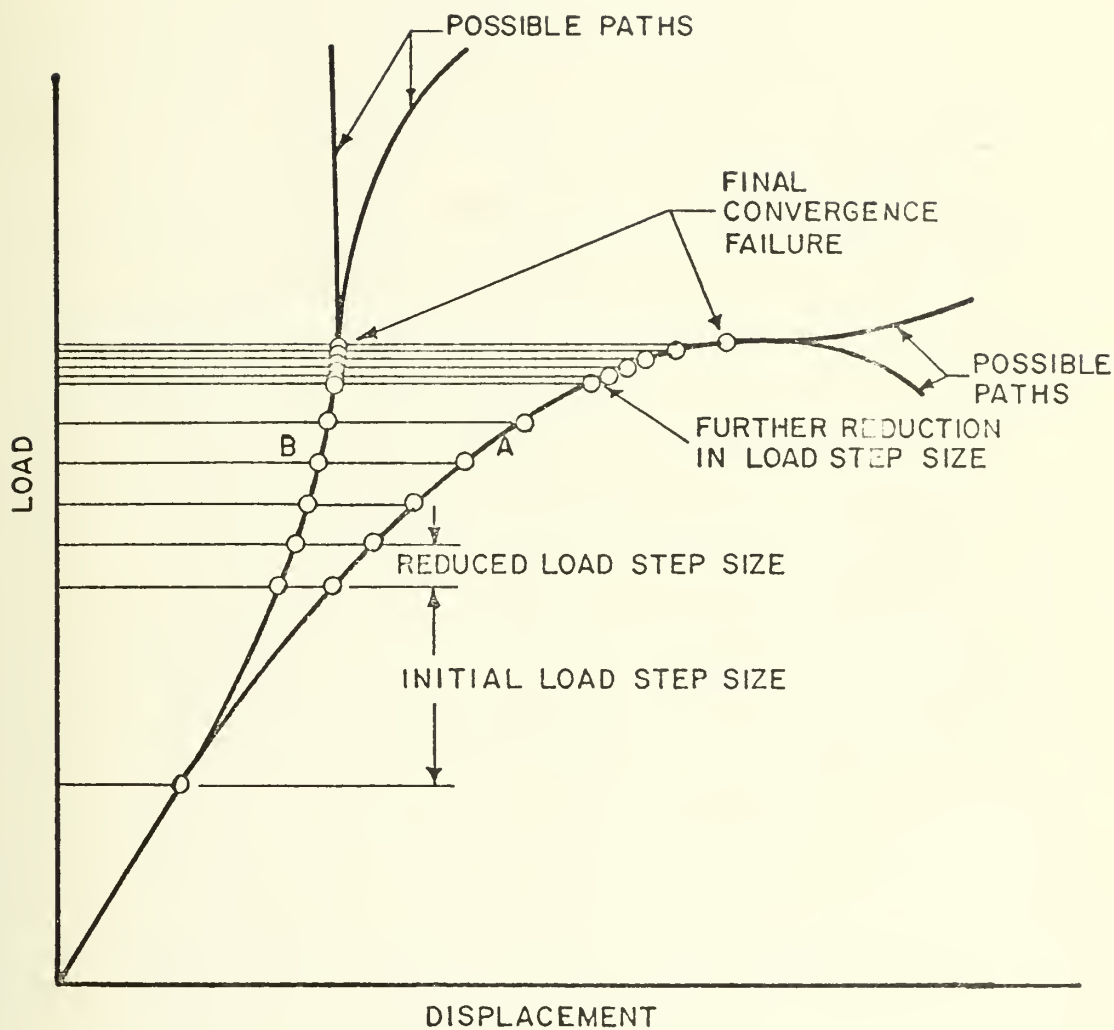
Since the method of solution is based on the pseudo load approach, the shell reacts equally, in a linear fashion, to any change in either the applied load or the pseudo load. Thus, failure of the solution to converge in any harmonic can be attributed to two types of nonlinear behavior, both of which are illustrated in Figure 3. Referring to the figure, curve A experiences an inflection point or a maximum. Either condition causes a zero or nearly zero slope and a convergence failure. This curve is typical of softening nonlinearity. Curve B, on the other hand, is typical of a stiffening nonlinearity and a convergence failure will occur when the slope becomes large. It is necessary, then, to examine the load-displacement behavior of the shell to determine the cause of convergence failure. A detailed discussion of the theory and implementation of SATANS can be found on pages 8 through 29 and in Appendices B, C and D of Ref. 3, and on pages 8 through 28, pages 56 through 61 and page 100 of Ref. 4.

### C. USER PREPARED SUBROUTINES

Five small subroutines describing the shell geometry, the stiffnesses, the loading (physical and/or thermal), and the initial conditions (in the dynamic case) must be prepared by the user. Complete descriptions for the







NONLINEAR BEHAVIOR AFFECTING CONVERGENCE

FIGURE 3



preparation of these subroutines can be found on pages 34 through 38 of Ref. 4.



### III. CONSTRUCTION OF SATANS-I

Stein [Ref. 10] observes that a basic impediment to the widespread use of existing computer programs is the difficult and laborious process of assimilation of a program's basic theory, its implementation and its use by a prospective researcher. He also warns the 'unwary analyst' of the dangers inherent in computer output, which is a 'blizzard of numbers.' As a consequence, SATANS is continually being modified in an attempt to make it more usable. The most recent modifications made for this purpose are described in this section. This new version of SATANS is called SATANS-I.

#### A. PACKAGING

SATANS has been reorganized to allow 99% of the code to be prepackaged for repeated use by researchers. Compiled versions of all subroutines and main controlling routines can now be placed on a disk, in a data cell or on a magnetic tape, allowing the user to 'submit' only the user written subroutines and input data. A complete listing of this storable package is given in Appendix E.

#### B. PLOTTING ROUTINE

A great advantage is gained if the computer output can be presented in graphical format. Such plots, however, are often generated using mechanical or photo-electronic devices which are not universally usable. Consequently, SATANS has



been enhanced with an equipment-independent plot package utilizing self-contained subroutines and the high-speed line printer.

The main program listed in Ref. 4 could not be modified to incorporate the logic and control for a graphical ability as it then exceeded the capability of the FORTRAN-H compiler. Therefore, the main program of Ref. 4 has been replaced by a new main program and two subroutines described as follows:

SATANS - This is the new 'main.' It reads all data cards, prepares the title page of output and passes control to either of two basic controlling subroutines.

STATIC - This is the controlling subroutine for a static analysis. It conducts initialization, establishes geometry, stiffness, loading and boundary conditions, controls plotting of input information and controls the solution procedure.

DYNAMC - This is the controlling subroutine for a dynamic analysis and it operates in a fashion similar to subroutine STATIC.

The graphical ability is obtained by the introduction of two controlling subroutines, PLOT1 and PLOT2, four plotting subroutines, PLOTIT, SCALIT, ROUND and DRAWIT,<sup>1</sup> and modification of subroutine OUTPUT for the selection of output data for plotting. A single data card with request information

---

<sup>1</sup>The four plotting subroutines are slightly modified versions of those contained in Ref. 11 under the listing "JS UTPILOT."





is required to generate the plots. The plotting routines will handle a maximum of 100 stations. This routine is included in the listing given in Appendix E.

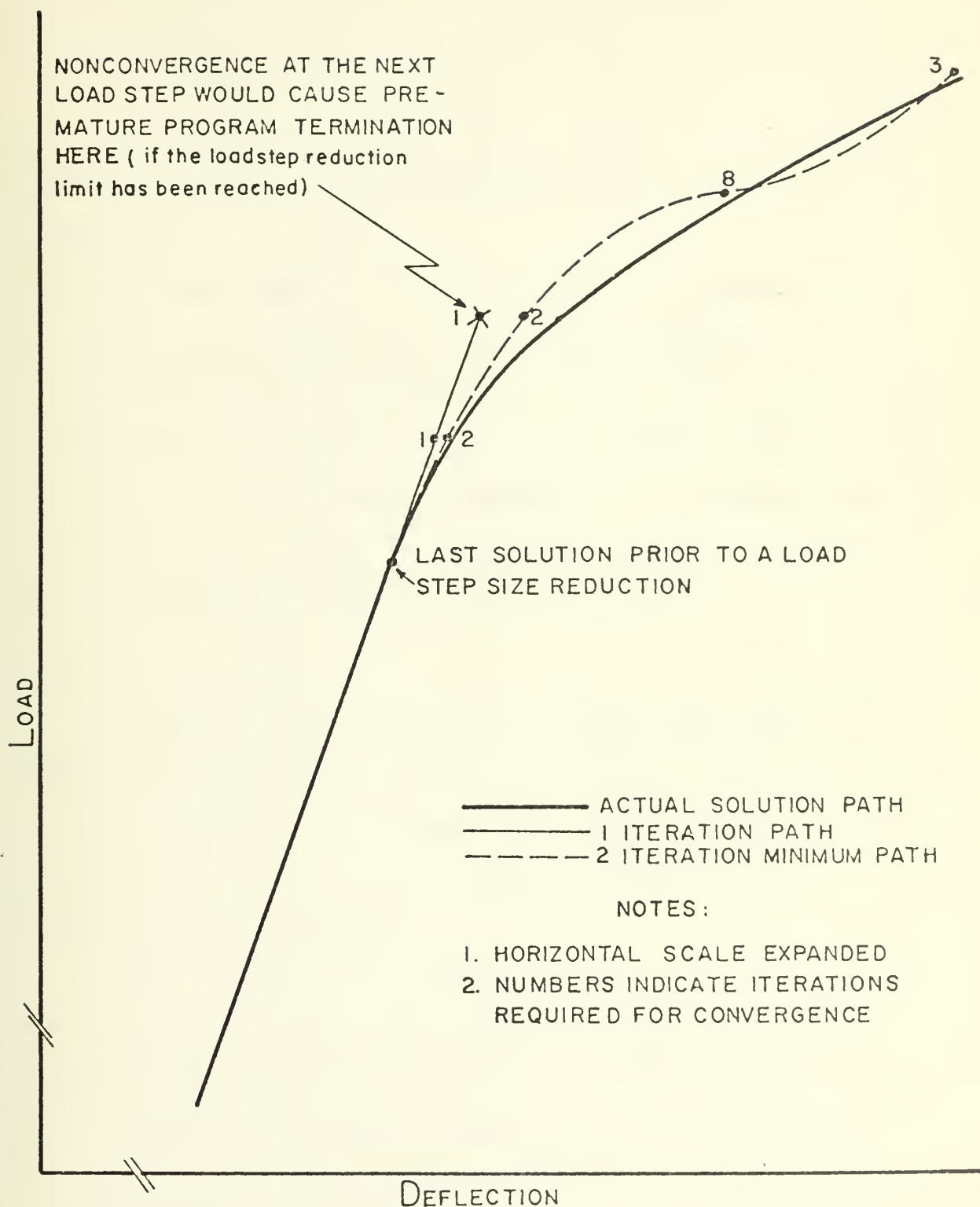
### C. MISCELLANEOUS ALTERATIONS

The iteration lower limit has been raised to two iterations. This change was introduced because it was noted that immediately after a load step size reduction, several consecutive solutions were obtained in one iteration, a completely linear process. This was then followed by non-convergence and, in some instances, premature program termination. Setting a minimum of two iterations automatically introduces nonlinearity into each load step and appears to solve this problem, as illustrated in Figure 4.

A quadratic extrapolation technique was investigated using a static analysis of the highly nonlinear shallow spherical cap. No gain in solution accuracy was seen and a price was paid in program execution time due to approximately 10% greater total iterations required, not to mention the increased storage space requirement. This phenomenon is exactly as observed by Stricklin et al [Ref. 12], hence the linear extrapolation technique has been retained.

Since boundary loads are introduced through the boundary conditions and since the program considers the boundary conditions to be the same in every harmonic, changes indicated in Appendix B of Ref. 5 are permanently incorporated into the program. This alteration causes the applied





PREMATURE PROGRAM TERMINATION

FIGURE 4



loading at a boundary to be taken in the zeroeth harmonic only, i.e., when  $n=0$ .

All 'COMMON' statements have been ordered and separated and some slightly modified. This alteration allows easier reading and correlation of FORTRAN variables with specific subroutines.

The output ability has been expanded to allow printed data (and plots) at up to 36 vice six meridians.

In the case of a shell with an initial (or a final) pole, determination of the shear force at the pole in the  $n=1$  harmonic has been deemed an inconsequential and lengthy computation and has been removed. Appropriate changes have been made in subroutines INLPOL, FNLPOL and OUTPUT.

#### D. USE OF SATANS-I

Instructions for preparation of input data cards for SATANS-I are contained in Appendix C and the initiating main program and user written subroutines appear in Appendix D. Appendices D and E contain a complete listing of the computer program, SATANS-I.

SATANS-I requires 206 k-bytes of main core when run on an IBM-360/67 computer under OS/MVT and compiled by the FORTRAN-H compiler at optimization level 2. Execution times are the same as for SATANS unless plotting is requested, and then is increased approximately 0.01 seconds for each 100 point plot generated.



#### IV. CONSTRUCTION OF SATANS-II

As discussed previously, a serious impediment to the consideration of initial imperfections by Dantone [Ref. 57] was the requirement that the imperfections be symmetric about a datum meridian. This restriction results from the fact that all dependent variables were expanded in a single sine or cosine series. The analysis presented in this section removes this restriction by introducing the use of full trigonometric series expansions for the dependent variables, and then modifies the resulting new relations where required for the introduction of initial imperfections. The computer program that incorporates these changes is a modification to SATANS-I, called SATANS-II.

##### A. INTRODUCTION OF FULL TRIGONOMETRIC SERIES EXPANSIONS

The original assumption by Ball [Ref. 37] was that a normal pressure load could be expressed in a Fourier cosine series as

$$q = (\sigma_0 h_0 / E_0) \sum_0^{\infty} p^{(n)} \cos n\theta \quad (1)$$

where  $\sigma_0$  = the reference stress level,

$h_0$  = the reference thickness,

$E_0$  = the reference Young's modulus,

$n$  = the Fourier index, or harmonic,

and  $p$  = the nondimensional Fourier coefficient of the normal pressure load. The normal displacement  $W$





corresponding to this pressure was taken as

$$W = (a\sigma_0/E_0) \sum_0^{\infty} w^{(n)} \cos n\theta \quad (2)$$

where  $a$  is the shell characteristic length and  $w$  is the nondimensional series coefficient of the normal displacement. For a completely arbitrary case, representing  $q$  and  $W$  with the complete Fourier series gives

$$q = (\sigma_0 h_0/E_0) \left( \sum_0^{\infty} p^1(n) \cos n\theta + \sum_1^{\infty} p^2(n) \sin n\theta \right) \quad (3)$$

and

$$W = (a\sigma_0/E_0) \left( \sum_0^{\infty} w^1(n) \cos n\theta + \sum_1^{\infty} w^2(n) \sin n\theta \right) \quad (4)$$

where superscript <sup>1</sup> indicates a previously existing coefficient and superscript <sup>2</sup> indicates a new coefficient. Similar series expansions can be written for the other pressures, displacements, etc.

The nonlinear terms associated with the full series are illustrated by  $\phi_s^2$ ,

$$\begin{aligned} \phi_s^2 = (\sigma_0/E_0)^2 & \left\{ \left( \sum_0^{\infty} \phi_s^1(n) \cos n\theta \right)^2 + \left( \sum_1^{\infty} \phi_s^2(n) \sin n\theta \right)^2 \right. \\ & \left. + 2 \left( \sum_0^{\infty} \phi_s^1(n) \cos n\theta \right) \left( \sum_1^{\infty} \phi_s^2(n) \sin n\theta \right) \right\} \quad (5) \end{aligned}$$

where the  $\phi_s$  are the nondimensional series coefficients of



the meridional rotation, given as

$$\begin{aligned}\phi_S^1(n) &= (-w^1(n))' + \omega_S u^1(n) \\ \phi_S^2(n) &= (-w^2(n))' + \omega_S u^2(n)\end{aligned}\tag{6}$$

Originally, in Refs. 3 and 4, the nonlinear term  $\phi_S^2$  was represented as

$$\phi_S^2 = (\sigma_0/E_0)^2 \left( \sum_0^\infty \phi_S^1(n) \cos n\theta \right)^2 \equiv \sigma_0/E_0 \sum_0^\infty \beta_S^1(n) \cos n\theta \tag{7}$$

since

$$\cos(n\theta)\cos(m\theta) = \frac{1}{2}\cos(n-m)\theta + \frac{1}{2}\cos(n+m)\theta$$

The  $\beta_S^1(n)$  term contains the products of all the  $\phi_S$ 's whose harmonic sum or difference equals  $n$ . There are now two additional terms in equation (5). These can be represented as

$$(\sigma_0/E_0)^2 \left( \sum_1^\infty \phi_S^2(n) \sin n\theta \right)^2 \equiv \sigma_0/E_0 \sum_1^\infty \beta_S^2(n) \cos n\theta \tag{8}$$

and

$$\begin{aligned}2(\sigma_0/E_0)^2 \left( \sum_0^\infty \phi_S^1(n) \cos n\theta \right) \left( \sum_1^\infty \phi_S^2(n) \sin n\theta \right) \\ \equiv \sigma_0/E_0 \sum_1^\infty \beta_S^{12}(n) \sin n\theta\end{aligned}\tag{9}$$

where superscript  $^{12}$  indicates the product of a previously existing coefficient and a new coefficient.



Thus,

$$\begin{aligned} \Phi_S^2 = \sigma_0/E_0 \left( \sum_0^{\infty} \beta_S^1(n) \cos n\theta + \sum_0^{\infty} \beta_S^2(n) \cos n\theta \right. \\ \left. + \sum_1^{\infty} \beta_S^{12}(n) \sin n\theta \right) \end{aligned} \quad (10)$$

Similarly, the nonlinear term  $\Phi_\theta^2$  (and also  $\Phi^2$  since it is of the same form) is given by

$$\begin{aligned} \Phi_\theta^2 = (\sigma_0/E_0)^2 \left\{ \left( \sum_1^{\infty} \phi_\theta^1(n) \sin n\theta \right)^2 + \left( \sum_0^{\infty} \phi_\theta^2(n) \cos n\theta \right)^2 \right. \\ \left. + 2 \left( \sum_1^{\infty} \phi_\theta^1(n) \sin n\theta \right) \left( \sum_0^{\infty} \phi_\theta^2(n) \cos n\theta \right) \right\} \end{aligned} \quad (11)$$

which can be represented as

$$\begin{aligned} \Phi_\theta^2 = \sigma_0/E_0 \left( \sum_0^{\infty} \beta_\theta^1(n) \cos n\theta + \sum_0^{\infty} \beta_\theta^2(n) \cos n\theta \right. \\ \left. + \sum_1^{\infty} \beta_\theta^{12}(n) \sin n\theta \right) \end{aligned} \quad (12)$$

The nonlinear term  $\Phi_S \Phi_\theta$  is given by

$$\begin{aligned} \Phi_S \Phi_\theta = (\sigma_0/E_0)^2 \left\{ \left( \sum_0^{\infty} \phi_S^1(n) \cos n\theta \right) \left( \sum_1^{\infty} \phi_\theta^1(n) \sin n\theta \right) \right. \\ + \left( \sum_0^{\infty} \phi_S^1(n) \cos n\theta \right) \left( \sum_0^{\infty} \phi_\theta^2(n) \cos n\theta \right) \\ + \left( \sum_1^{\infty} \phi_S^2(n) \sin n\theta \right) \left( \sum_1^{\infty} \phi_\theta^1(n) \sin n\theta \right) \\ \left. + \left( \sum_1^{\infty} \phi_S^2(n) \sin n\theta \right) \left( \sum_0^{\infty} \phi_\theta^2(n) \cos n\theta \right) \right\} \end{aligned} \quad (13)$$



which can be represented as

$$\begin{aligned} \phi_s \phi_\theta = \sigma_o/E_o \left( \sum_1^{\infty} \beta_{s\theta}^{1(n)} \sin n\theta + \sum_0^{\infty} \beta_{s\theta}^{1,2(n)} \cos n\theta \right. \\ \left. + \sum_0^{\infty} \beta_{s\theta}^{2(n)} \sin n\theta \right) \end{aligned} \quad (14)$$

Following this scheme, similar expressions can be obtained for the remaining nonlinear terms  $\phi_s N_s$ ,  $\phi_\theta N_\theta$ ,  $\phi_s N_{s\theta}$ ,  $\phi_\theta N_{\theta s}$ ,  $\phi N_s$  and  $\phi N_\theta$ .

All of the nonlinear terms fall into one of the three categories  $\cos(k\theta)\cos(\ell\theta)$ ,  $\sin(k\theta)\sin(\ell\theta)$  or  $\cos(k\theta)\sin(\ell\theta)$ . Since these three forms were already accounted for in SATANS, there was no need to develop any new routines for the full series expansions. It was only necessary to introduce each new nonlinear term into the appropriate existing summation in subroutines PHIBET and TEAETA.

## B. INTRODUCTION OF INITIAL IMPERFECTIONS

The initial imperfections only influence the nonlinear terms in the equations. The strain-displacement relationships used in this analysis are

$$\begin{aligned} \epsilon_s &= U' + W/R_s + \frac{1}{2}(\phi_s^2 + \phi^2) \\ \epsilon_\theta &= V'/r + r'U/r + W/R_\theta + \frac{1}{2}(\phi_\theta^2 + \phi^2) \\ \epsilon_{s\theta} &= \frac{1}{2}(V' + U'/r - r'V/r + \phi_s \phi_\theta) \end{aligned} \quad (15)$$





where

$$\begin{aligned}
 \phi_s &= -W' + U/R_s \\
 \phi_\theta &= -W^*/r + V/R_\theta \\
 \phi &= \frac{1}{2}(V' + r'V/r - U^*/r)
 \end{aligned} \tag{16}$$

and where  $\epsilon_s$ ,  $\epsilon_\theta$ ,  $\epsilon_{s\theta}$  represent the reference surface strains,  $\phi_s$ ,  $\phi_\theta$ ,  $\phi$  represent the reference surface rotations, and superscript primes and dots represent partial differentiation with respect to  $s$  and  $\theta$ , respectively.

Consider a shell whose geometry differs slightly from a shell of revolution. For this imperfect shell, a deviation from a specific shape occurs in the form of a transverse displacement,  $\bar{W}$ . This  $\bar{W}$  produces no strain. Defining  $W^*$  as a total displacement,

$$W^* \equiv W + \bar{W} \tag{17}$$

and replacing  $W$  in equations (15) with  $W^*$  of equation (17) gives

$$\begin{aligned}
 \epsilon_s + \bar{\epsilon}_s &= U' + W^*/R_s + \frac{1}{2}(\phi_s^{*2} + \phi^2) \\
 \epsilon_\theta + \bar{\epsilon}_\theta &= V^*/r + r'U/r + W^*/R_\theta + \frac{1}{2}(\phi_\theta^{*2} + \phi^2) \\
 \epsilon_{s\theta} + \bar{\epsilon}_{s\theta} &= \frac{1}{2}(V' + U^*/r - r'V/r + \phi_s^*\phi_\theta^*)
 \end{aligned} \tag{18}$$

where

$$\begin{aligned}
 \phi_s^* &= -W^{*'} + U/R_s \\
 \phi_\theta^* &= -W^{*\cdot}/r + V/R_\theta
 \end{aligned} \tag{19}$$



and  $\bar{\epsilon}_s$ ,  $\bar{\epsilon}_\theta$  and  $\bar{\epsilon}_{s\theta}$  are the pseudo strains due to  $\bar{W}$  only.

When  $U = V = W = 0$ , then  $W^* = \bar{W}$ , and  $\epsilon_s \equiv \epsilon_\theta \equiv \epsilon_{s\theta} \equiv 0$ .

Substituting these relationships into equation (18), solving for  $\bar{\epsilon}_s$ ,  $\bar{\epsilon}_\theta$ ,  $\bar{\epsilon}_{s\theta}$  and placing these terms in equations (16) lead to

$$\epsilon_s = U' + W^*/R_s + \frac{1}{2}(\phi_s^{*2} + \phi^2) - \bar{W}/R_s - \frac{1}{2}(\bar{W}')^2 \quad (20)$$

$$\epsilon_\theta = V'/r + r'U/r + W^*/R_\theta + \frac{1}{2}(\phi_\theta^{*2} + \phi^2) - \bar{W}/R_\theta - \frac{1}{2}(\bar{W}')^2/r$$

$$\epsilon_{s\theta} = \frac{1}{2}(V' + U'/r - r'V/r + \phi_s^*\phi_\theta^* - \bar{W}'\bar{W}'/r)$$

Expansion of equations (20) making use of equations (16), (17) and (19) lead to

$$\epsilon_s = U' + W/R_s + \frac{1}{2}(\phi_s^2 + \phi^2) - \{\bar{W}'\phi_s\}$$

$$\epsilon_\theta = V'/r + r'U/r + W/R_\theta + \frac{1}{2}(\phi_\theta^2 + \phi^2) - \{\bar{W}'\phi_\theta/r\} \quad (21)$$

$$\epsilon_{s\theta} = \frac{1}{2}(V' + U'/r - r'V/r + \phi_s\phi_\theta - \{\bar{W}'\phi_\theta + \bar{W}'\phi_s/r\})$$

where the terms enclosed in braces are the newly generated terms due to the imperfections, and

$$\phi_s^* = \phi_s - \{\bar{W}'\} \quad (22)$$

$$\phi_\theta^* = \phi_\theta - \{\bar{W}'/r\}$$

The presence of imperfections has no effect on the changes of curvatures since the curvature-displacement relations are linear.



Expressing the imperfection partial derivatives  $-\bar{W}'$  and  $-\bar{W}'/r$  as imperfection rotations  $\bar{\Phi}_S$  and  $\bar{\Phi}_\theta$ , the strain-displacement equations (21) can be expressed as

$$\begin{aligned}\epsilon_S &= U' + W/R_S + \frac{1}{2}(\phi_S^2 + \{2\phi_S \bar{\Phi}_S\} + \phi^2) \\ \epsilon_\theta &= V'/r + r'U/r + W/R_\theta + \frac{1}{2}(\phi_\theta^2 + \{2\phi_\theta \bar{\Phi}_\theta\} + \phi^2) \quad (23) \\ \epsilon_{S\theta} &= \frac{1}{2}(V' + U'/r - \phi_S \phi_\theta + \{\phi_\theta \bar{\Phi}_S + \phi_S \bar{\Phi}_\theta\})\end{aligned}$$

where the terms in braces are the newly generated terms. Imperfection rotations also affect the nonlinear term,  $\phi_S N_S$  (and the others listed after equation (14)). For these terms, the reference surface rotations  $\phi_S$  and  $\phi_\theta$  must be replaced by  $\phi_S^*$  and  $\phi_\theta^*$  of equations (22).

To illustrate the procedure which is used in the following section to introduce the initial imperfection rotations, consider the single series expansion, equation (7), repeated here,

$$\phi_S^2 = (\sigma_0/E_0)^2 \left( \sum_0^\infty \phi_S^{1(n)} \cos n\theta \right)^2 \equiv \sigma_0/E_0 \sum_0^\infty \beta_S^{1(n)} \cos n\theta \quad (7)$$

Modifying this equation to include the effect of initial imperfections indicated by equations (23) results in

$$\begin{aligned}\phi_S^2 + \{2\phi_S \bar{\Phi}_S\} &= (\sigma_0/E_0)^2 \left[ \left( \sum_0^\infty \phi_S^{1(n)} \cos n\theta \right)^2 \right. \\ &\quad \left. + 2 \left( \sum_0^\infty \phi_S^{1(n)} \cos n\theta \right) \left( \sum_0^\infty \bar{\Phi}_S^{1(n)} \cos n\theta \right) \right] \quad (24) \\ &\equiv \sigma_0/E_0 \sum_0^\infty \beta_S^{*1(n)} \cos n\theta\end{aligned}$$



A redefinition of  $\beta_s$  to include the cross-product term is now required, along with redefinitions of the other  $\beta$  terms, and the  $\eta$  terms in the other nonlinear term expressions. A redefinition of these terms alone is sufficient for the introduction of initial imperfections into a SATANS analysis where only the single series expansions are used. This was the thrust of the thesis by Dantone.

### C. COMBINATION OF FULL TRIGONOMETRIC SERIES EXPANSIONS AND INITIAL IMPERFECTIONS

Consider that for every meridional rotation  $\phi_s$ , where

$$\phi_s = (\sigma_0/E_0)^2 \left( \sum_0^{\infty} \phi_s^1(n) \cos n\theta + \sum_1^{\infty} \phi_s^2(n) \sin n\theta \right) \quad (25)$$

there exists an initial meridional imperfection rotation  $\bar{\phi}_s$ , defined as

$$\bar{\phi}_s = (\sigma_0/E_0)^2 \left( \sum_0^{\infty} \bar{\phi}_s^1(n) \cos n\theta + \sum_1^{\infty} \bar{\phi}_s^2(n) \sin n\theta \right) \quad (26)$$

The nonlinear term  $\phi_s^2$ , previously given by equation (5), now becomes  $(\phi_s^2 + 2\phi_s\bar{\phi}_s)$ , according to equation (23), where  $\phi_s^2$  is given by equation (5) and  $\phi_s\bar{\phi}_s$  is the product of equations (25) and (26), as illustrated for the single series expansion in equation (24). All the nonlinear terms of equations (15) have been converted to those in equation (23) for the full series expansions and the resulting relations are given in Appendix A. The definitions of the  $\beta$  terms (given previously in Ref. 3) have been modified to include the





effects of both full series expansions and initial imperfection presence.

The remaining nonlinear terms (those listed after equation (14) ) also require modification but are of simpler form since only the first power of the rotation is involved. A redefinition of the  $\eta$  terms to include the effects of full series expansions and appropriate initial imperfection rotations has also been made.

In this manner, the validity of the strain-displacement equations (equations (5) of Ref. 3 and equations (15) of this report) and the equilibrium equations (equations (8) of Ref. 3) is retained. Introduction of full series expansions and initial imperfections in the nonlinear terms was accomplished by a redefinition of the  $\beta$  and  $\eta$  terms, which are the nondimensional coefficients for the nonlinear terms in the strain-displacement and equilibrium equations, respectively.

#### D. SUBROUTINE MODIFICATIONS

Introduction of the full series into the program was implemented by use of negative index numbers for the new sine or cosine portions of the expansions (the terms with the superscript <sup>2</sup>). With the requirement that the axisymmetric harmonic ( $n=0$ ) be included, the program was expanded to handle a maximum of 25 modes, i.e., the zeroeth harmonic ( $n=0$ ) plus twelve other harmonics (positive and negative). Each positive index and each negative index will be referred to as a mode, i.e., the harmonic  $n=5$  has two modes,  $-5$



and +5. A typical correspondence between harmonic, mode and Fourier index is given in Table I. Harmonic zero ( $n=0$ ) and any combination of up to twelve harmonics may be included in the analysis. The positive values of NN in Table I are the modes analyzed in SATANS and SATANS-I. The negative values of NN are those modes added to incorporate the full series expansions in SATANS-II. Note that  $n=0$  is the first mode, and that the negative value is always the first mode of a pair of modes. This is a requirement.

TABLE I

HARMONIC, MODE AND FOURIER INDEX CORRESPONDENCE

HARMONIC n	MODE	FOURIER INDEX	FORTRAN ASSIGNMENT STATEMENT IN SUBROUTINE PLOAD OR TLOAD
0	1	0	NN(1)=0
1	2	-1	NN(2)=-1
	3	+1	NN(3)=+1
2	4	-2	NN(4)=-2
	5	+2	NN(5)=+2
5	6	-5	NN(6)=-5
	7	+5	NN(7)=+5
.	.	.	.
.	.	.	.
.	.	.	.
18	24	-18	NN(24)=-18
	25	+18	NN(25)=+18



Seven subroutines of SATANS-I required changes to incorporate the full trigonometric series expansions and the initial imperfections.

Subroutine PHIBET calculates the  $\phi$ 's and carries out the summation procedures for calculating the  $\beta$  nonlinear terms. Since extensive modification was required, the subroutine was altered such that those sections handling the full trigonometric expansions and imperfections are entered only if required, i.e., if a full series analysis is necessary.

Subroutine TEAETA calculates the inplane forces and the  $\eta$  nonlinear terms. It was also extensively modified, again, utilizing new sections only if required.

The subroutine MODES, a highly complex procedure for determining modal coupling required minimal alteration since each unique mode number is stored at every, or every other storage location, depending on use of SATANS-I or SATANS-II, respectively. Each unique harmonic is accessed, then, by an appropriate step size change in the controlling loops.

The subroutine OUTPUT required the addition of a section to include the new half of the trigonometric series in the generation of a summed solution at a specified meridian.

The subroutines POLE, INLPOL and FNLPOL compute the solution at an initial or a final pole. Due to the computation of pole conditions based on  $n$ , which now has positive and negative values, these routines were modified



accordingly. Effectively, the only change in the equations presented in Appendix D of Ref. 3 involve a replacement of  $n$  by  $-n$  where appropriate.

A complete listing of these seven modified subroutines is given in Appendix F.

#### E. SATANS-II

To modify SATANS-I to handle completely arbitrary loading and initial imperfections, the following steps must be performed.

1. Replace subroutines PHIBET, TEAETA, MODES, OUTPUT, POLE, INLPOL and FNLPOL with those in Appendix F.
2. Replace the affected COMMON statements in Appendices D and E with those listed in Appendix F.
3. Add subroutine IMPERF, also listed in Appendix F. This subroutine contains the values of the imperfection rotation coefficients,  $\bar{\phi}_s$  and  $\bar{\phi}_\theta$ . Instructions for actual preparation of these coefficients will be discussed in detail in section V. If imperfections are not to be considered, the  $\bar{\phi}_s$  and  $\bar{\phi}_\theta$  are never accessed.
4. In Appendix E, make the following additions after the card indicated:

<u>Subroutine</u>	<u>After Card Number</u>	<u>Insert</u>
DYNAMC	00002270	CALL IMPERF
STATIC	00002230	CALL IMPERF
PMATRX	00001100	IF(N(MN).LT.0)P(2,1,IJ)=-1.0
PMATRX	00002000	IF(N(MN).LT.0)ZFP1(2,2)=1.0
SATANS	00000380	READ(5,108)JUMP,MPERFS





SATANS            00001400       108 FORMAT(2I5)

5. In Appendix E, modify the following cards:

<u>Subroutine</u>	<u>Card Number</u>	<u>Should Read</u>
DYNAMC	00000800	DIMENSION VBAR(25),AVB(25)
PMATRX	00000900	NN=IABS(N(MN))
PMATRX	00001640	NN=IABS(N(MN))

6. In Appendix C, modify the data preparation instructions by adding a data card after card #4 according to the following format:

<u>Card</u>	<u>Column</u>	<u>Format</u>	<u>Item</u>	<u>Interpretation</u>
4.1	1-5	I5	JUMP	1 = single series expansion 2 = double series expansion
4.1	6-10	I5	MPERFS	0 = no imperfections 1 = imperfections

An initial imperfection solution requires the use of full series in the analysis. Specification of the parameter JUMP indicates whether the solution will be as in SATANS-I or will utilize the full trigonometric series expansions of SATANS-II. Specification of the parameter MPERFS indicates whether the analysis will include initial imperfections. Note that if MPERFS equals 1, JUMP must equal 2, but if JUMP equals 2, MPERFS may be either 1 or 0.

7. Add imperfection data just prior to the last card of the data deck. This data is to be placed in arrays PHIXB and PHITB.



## F. USE OF SATANS-II

After completing the changes in section IV.E, SATANS-II exists as a program capable of performing all the functions of SATANS-I with the following restrictions:

1. The number of meridional stations cannot exceed 100, ( $KMAX < 101$ ).
2. The number of modes cannot exceed 25, ( $MNMAX < 26$ ).
3. The product of meridional stations and modes cannot exceed 951, ( $KMAX * MNMAX < 952$ ).
4. Plotting ability is not available for the imperfection input data.

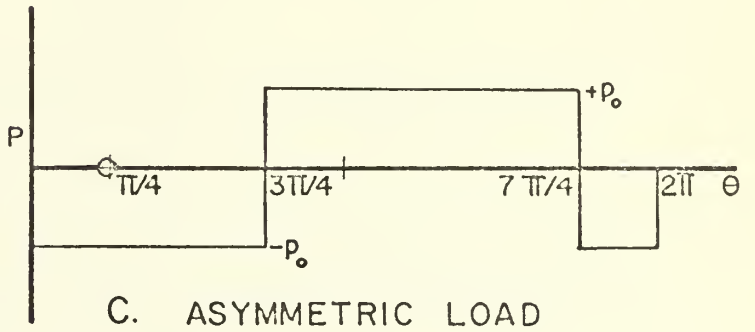
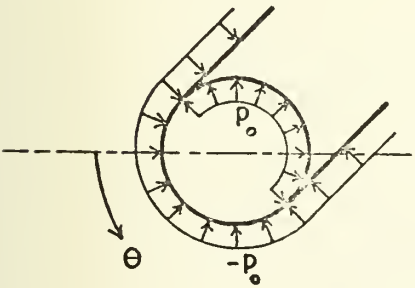
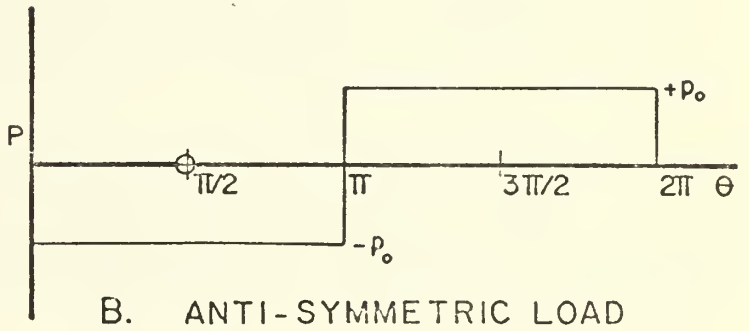
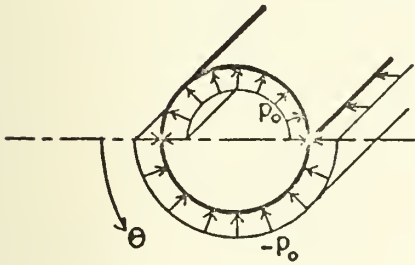
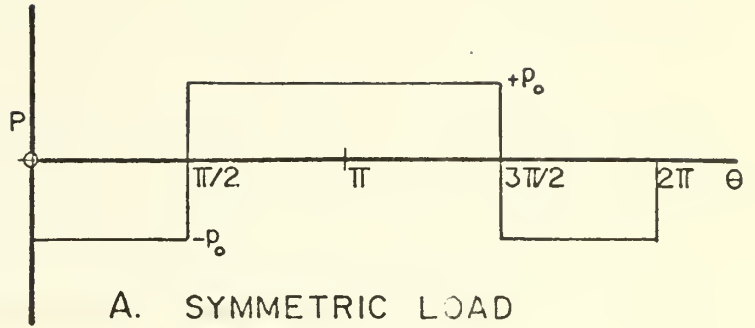
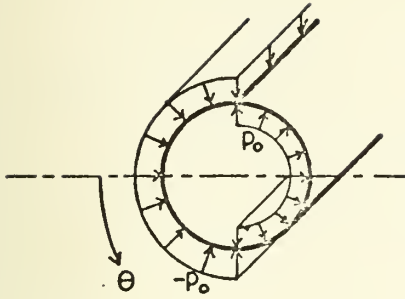
Specification of harmonics to be considered (accomplished in subroutine PLOAD or TLOAD) must include the axisymmetric harmonic ( $n=0$ ) and both negative and positive entries for any other harmonic, as indicated in Table I.

The instructions for the preparation of the input data are given in Appendix C. SATANS-II requires 426 k-bytes of main core on an IBM-360/67 computer when run under OS/MVT and when compiled by the FORTRAN-H compiler at optimization level 2. Execution times vary widely from four minutes for a 35 station and 3 mode analysis, up to 30 - 60 minutes for a 35 station and 25 mode analysis.

## G. VALIDITY OF SATANS-II

SATANS-II was checked for its ability to obtain a correct solution using the full series expansions. This check was made using a clamped cylindrical shell subjected to pressure loadings as described in Figure 5. A solution was





$\oplus$  = SOLUTION COMPARISON POINTS

SATANS-II CHECK LOADINGS  
FIGURE 5



obtained for the loading shown in Figure 5A with SATANS-I and the summed solution was printed at meridian  $\theta = 0^\circ$ . The cylinder was then analyzed by SATANS-II for the following three orientations:

1. Loading defined as in Figure 5A - a symmetric load.
2. Loading defined as in Figure 5B - an anti-symmetric load. In this case, the summed solution was printed at meridian  $\theta = 90^\circ$ .
3. Loading defined as in Figure 5C - a general load. In this case, the summed solution was printed at meridian  $\theta = 45^\circ$ .

Load definitions for the four check runs appear in Table II. In each case, the solution obtained by SATANS-II

TABLE II

FOURIER COEFFICIENTS FOR CHECK LOADINGS

MODE	FOURIER COEFFICIENTS OF APPLIED LOADING		
	SYMMETRIC	ANTI-SYMMETRIC	NONSYMMETRIC
0	0.0	0.0	0.0
-1	0.0	-63.66	-45.015
+1	-63.66	0.0	-45.015
-3	0.0	+21.22	+15.005
+3	+21.22	0.0	-15.005
-5	0.0	-12.73	+9.003
+5	-12.73	0.0	+9.003
-7	0.0	+9.095	-6.431
+7	+9.095	0.0	+6.431

Note: the coefficients are based on  $p_0 = 50$  psi.





agreed with the SATANS-I solution<sup>2</sup> through four significant digits.

---

<sup>2</sup>This reference to solution includes the load-deflection history, the ultimate nonconvergence level, and the displacement, force and moment distributions.



## V. IMPERFECT SHELL ANALYSIS

### A. PREPARATION OF THE IMPERFECTION DATA

With the developments of section IV implemented, SATANS-II requires only the Fourier coefficients of the imperfection data to conduct a nonlinear analysis. Recall from equation (26) that these Fourier coefficients,  $\bar{\Phi}_s$  and  $\bar{\Phi}_\theta$  are determined by knowledge of the actual imperfection rotations,  $\bar{\Phi}_s$  and  $\bar{\Phi}_\theta$ . Recall also from equation (22) that the imperfection rotations are given as

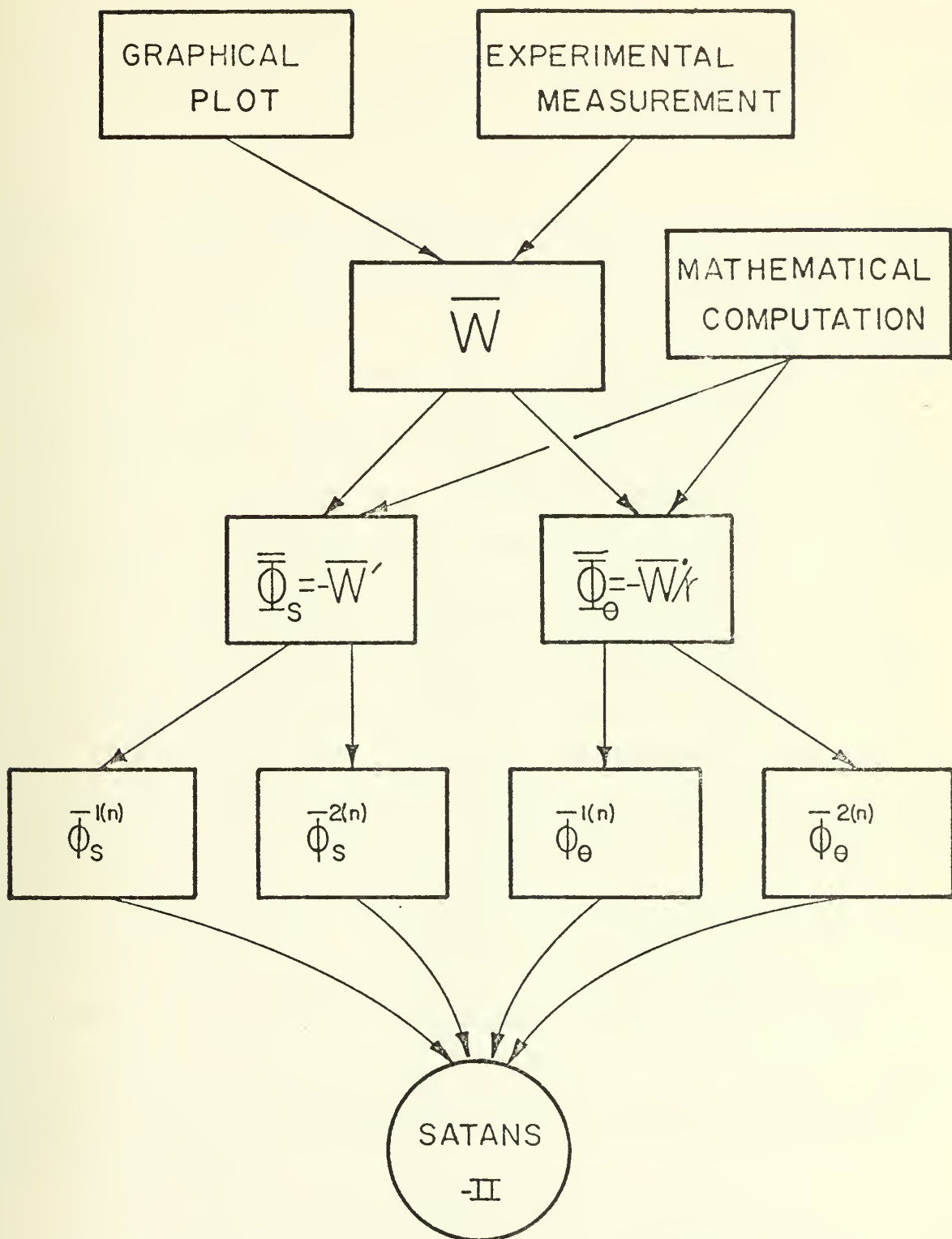
$$\begin{aligned}\bar{\Phi}_s &= -\bar{W}' \\ \bar{\Phi}_\theta &= -\bar{W}''/r\end{aligned}\tag{27}$$

This means that the imperfection rotation Fourier coefficients can be determined by knowledge of the initial normal deflection deviation,  $\bar{W}$ . This imperfection information can be obtained from a mathematical description, a graphical plot or from actual experimental measurement. A simplified data generation flow chart is presented in Figure 6.

#### 1. Data Generation by Mathematical Description

In a note on imperfect shallow spherical cap buckling, Kao [Ref. 13] analyzes a cap subjected to a mathematically defined dimple imperfection existing over one-quarter of the shell. The dimple is given by





SIMPLIFIED IMPERFECTION DATA GENERATION  
SCHEME

FIGURE 6



$$\bar{W} = 64 (s/L)^3 (1-s/L)^3 h \delta \cos 2\theta, \quad -45^\circ < \theta < 45^\circ$$

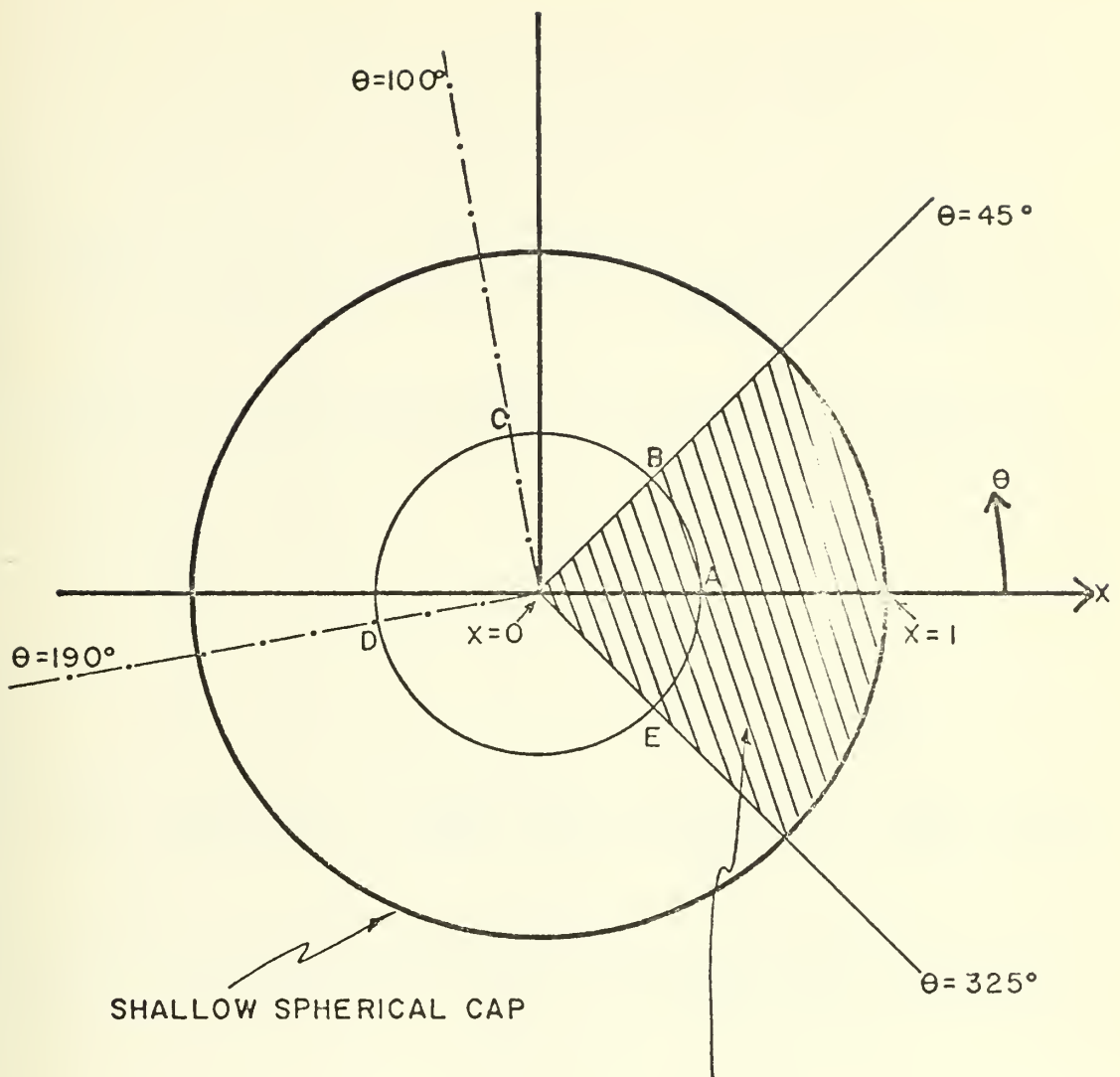
$$\bar{W} = 0, \quad 45^\circ < \theta < 325^\circ \quad (28)$$

where  $L$  is the total length of the shell meridian and where  $s/L$  ranges from 0 at the pole to 1 at the edge, and  $\delta$  is an intensity factor,  $0 \leq \delta \leq 1$ . The geometry of this problem is shown in Figure 7. Kao used a two-dimensional finite difference mesh of eight meridional and 16 circumferential stations in his analysis. A numerical model of, for example, 35 meridional stations and 25 modes would yield a SATANS-II solution of considerable accuracy. The discrete initial normal deflection deviations  $\bar{W}$  at each mesh point need not be computed, as partial differentiations of equation (28) give expressions directly solvable for discrete values of  $\bar{\Phi}_s$  and  $\bar{\Phi}_\theta$  for each  $s$  and  $\theta$ . Imperfection rotations at locations exterior to the affected area ( $-45^\circ < \theta < 45^\circ$ ) are zero. To illustrate, the meridional imperfection rotations that exist along the line ABCDEA of Figure 7 would appear as curve A of Figure 8. The discrete values generating this curve can easily be expanded into a full Fourier series and the resulting coefficients  $\bar{\Phi}_s^{(n)}$  inserted into SATANS-II for the analysis.

The imperfection of Figure 7 is symmetric about the meridian  $\theta = 0^\circ$ . As an example of a more complex imperfection, another dimple of the same form could be located in the region defined by  $100^\circ < \theta < 190^\circ$ . In this asymmetric case, the meridional imperfection rotations along line







IMPERFECT QUARTER WITH  
DIMPLE IMPERFECTION GIVEN BY

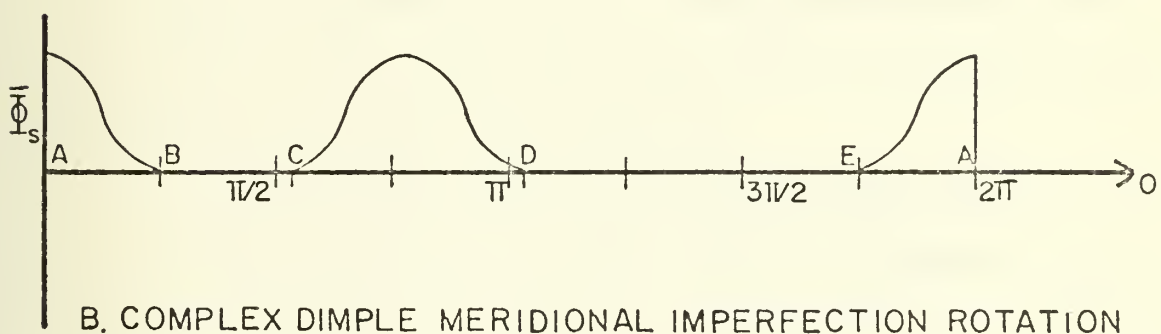
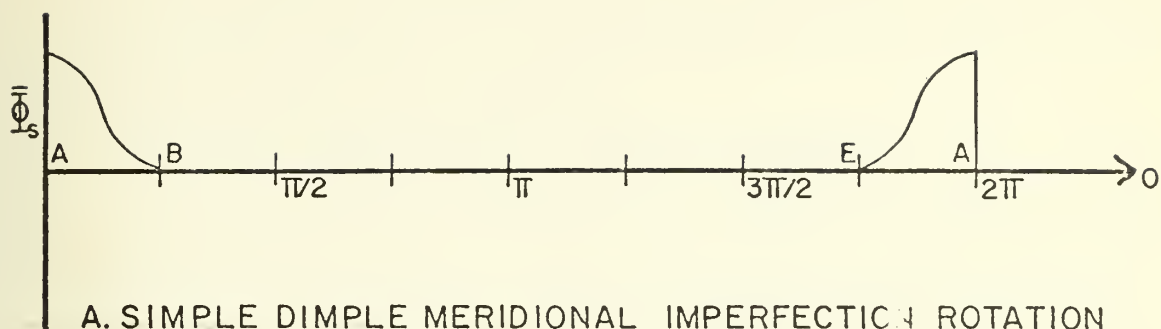
$$\bar{W}/h = 64x^3(1-x)^3 \cos 2\theta$$

WHERE  $x = s/L$

MATHEMATICAL IMPERFECTION GENERATION

FIGURE 7





MERIDIONAL IMPERFECTION ROTATION  
REPRESENTATION

FIGURE 8



ABCDEA of Figure 7 would now appear as curve B of Figure 8. The discrete values generating this curve can also be easily expanded into the full trigonometric series and its coefficients inserted into SATANS-II.

## 2. Data Generation by Graphical Plots

Graphical representations of  $\bar{W}$  can be easily constructed and the patterns are near limitless in design or location. Theoretical or actual creases, furrows or dents of any shape need only be graphed, the discrete imperfection displacements determined, the discrete imperfection rotations  $\bar{\Phi}_s$  and  $\bar{\Phi}_\theta$  computed via a finite differencing technique, the Fourier expansions performed and the resulting coefficients inserted into SATANS-II.

## 3. Data Generation by Experimental Measurement

Arbocz and Babcock [Ref. 6] have developed a means of mapping the topography of circular cylindrical shells, and can thus describe the deviations of an actual shell. The procedure, described in detail in Ref. 6, produces imperfection data in the form of nondimensional normal displacements from a perfectly circular cylinder. For the sample shells considered here, 49 data points were taken around each circumference and 29 equally-spaced circumferential traces were made. The first and last trace were 0.64 inches from the ends of the shell and the spacing between traces was 0.24 inches. Pertinent geometrical and material data concerning the shells of interest here is contained in Table III.



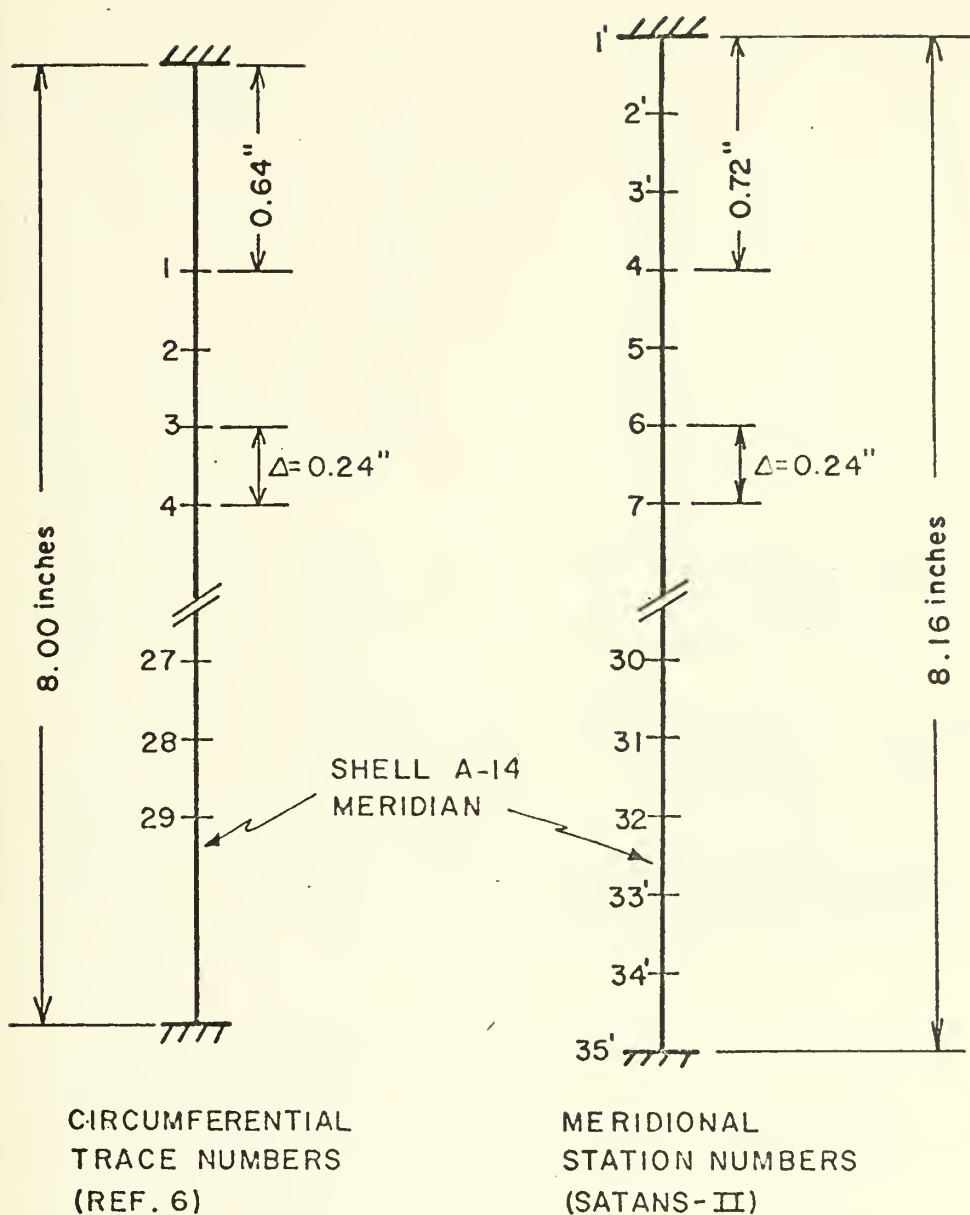
TABLE III  
IMPERFECT SHELL OVERALL CHARACTERISTICS

SHELL DESIGNATION	A-13	A-14
Radius	4.00"	4.00"
Length	8.00"	8.00"
Young's Modulus $\times 10^6$ , E	15.10 psi	15.80 psi
Wall thickness, h	0.00444"	0.00437"
Number of axial traces	29	29
Axial increment, $\Delta$	0.24"	0.24"
Number of data points	1421	1421

To prepare the imperfection data on shell A-14 for use by SATANS-II, the nondimensional deviations were first dimensionalized by the wall thickness. To retain the original axial increment of 0.24 inches between circumferential traces and to make the data compatible with a 35-station meridian, the shell length was increased by 0.08 inches at each end, or a total of 2% (See Figure 9). This required three additional traces at each end of the shell corresponding to stations 1, 2 and 3, and 33, 34 and 35. Data for the additional six circumferential traces were generated via the modified linear extrapolation procedure illustrated in Figure 10. At each of the 1,715 data points, the meridional and circumferential rotations were computed





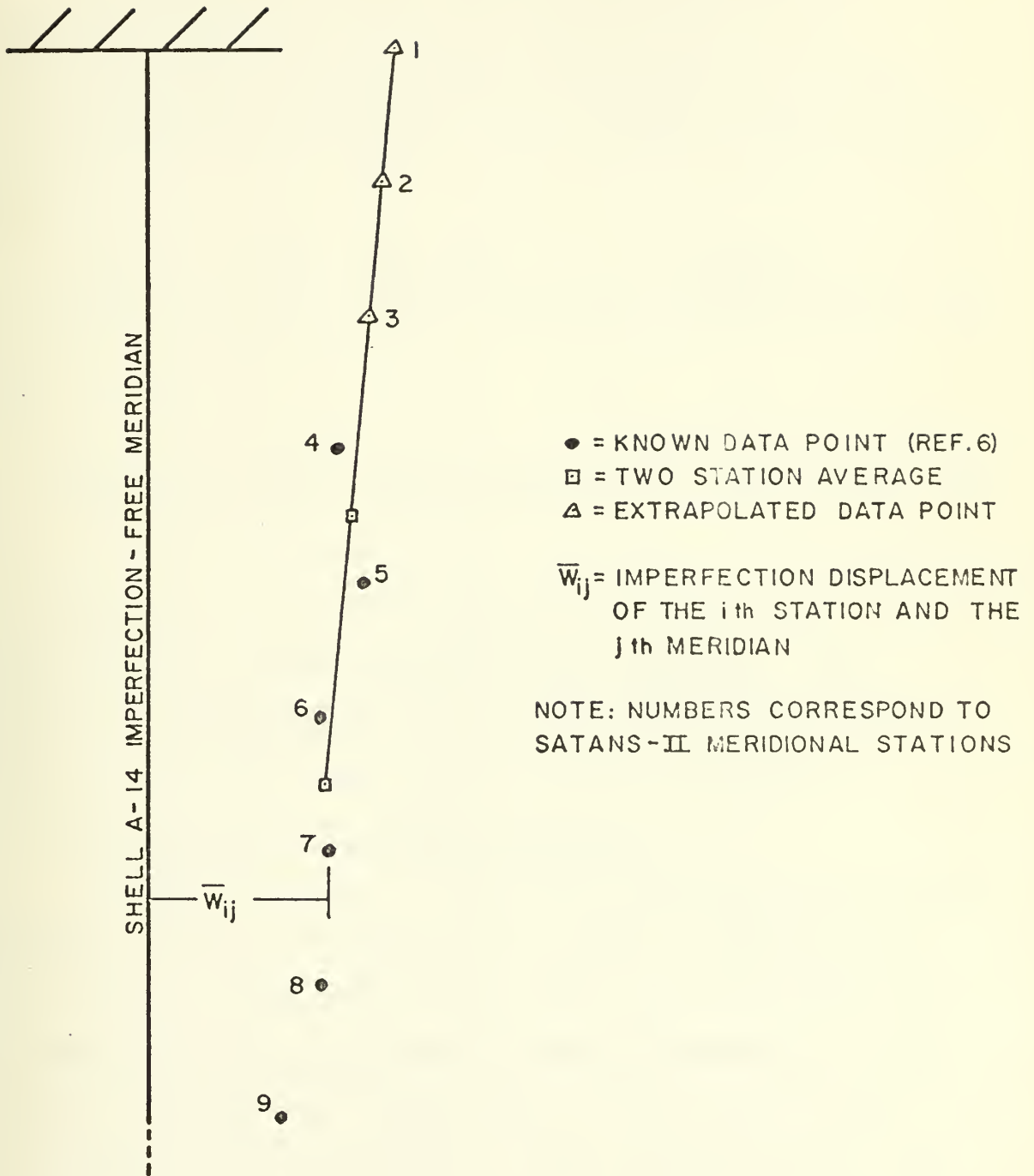


NOTE: Extrapolation required for data at primed stations

## CIRCUMFERENTIAL TRACE NUMBER AND MERIDIONAL STATION NUMBER CORRESPONDENCE

FIGURE 9





DATA POINT EXTRAPOLATION TECHNIQUE FOR  $\bar{w}$

FIGURE 10



using central finite differencing in the appropriate direction. After nondimensionalization according to the SATANS-II scheme, each circumferential vector of 48 meridional and 48 circumferential imperfection rotations was expanded via a periodogram into a Fourier series according to

$$(E_0/\sigma_0)\bar{\phi}_s = \bar{\phi}_s^{(0)} + \sum_1^{24} \bar{\phi}_s^c(n) \cos n\theta + \sum_1^{24} \bar{\phi}_s^s(n) \sin n\theta \quad (29)$$

and

$$(E_0/\sigma_0)\bar{\phi}_\theta = \bar{\phi}_\theta^{(0)} + \sum_1^{24} \bar{\phi}_\theta^c(n) \cos n\theta + \sum_1^{24} \bar{\phi}_\theta^s(n) \sin n\theta \quad (30)$$

At this point, the Fourier coefficients  $\bar{\phi}_s$  and  $\bar{\phi}_\theta$  are of proper form for direct insertion into SATANS-II. The computer program which performed the actual imperfection data processing for shell A-14 is given in Appendix G.

#### 4. Selection of Important Harmonics

Since the number of meridional stations was 35, the program maximum of 25 modes can be used in the analysis.<sup>3</sup> Note, however, that in equations (29) and (30), there are 49 modes describing the imperfections. Therefore, a selection of a maximum of 25 imperfection modes must be made. The harmonics to be considered in the analysis should include those critical to the shell and those significant in the imperfection. The description of the harmonic

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<sup>3</sup>Recall the restrictions given in section IV.F.



selection process for shell A-14 is given in a later section.

## B. BOUNDARY CONDITIONS

The testing configuration used by Arbocz and Babcock on the axially loaded cylinder is shown in Figure 11. The ends of the shell are attached to an end ring and a load cell with cerrelow, a low melting-point alloy. The ends of the shell are believed to be clamped so that

$$W = \phi_s = V = 0 \quad (31)$$

The axial load on the test specimen was applied by means of four screws located at the corners of the square end plates. At each load increment, the screws were adjusted to give as uniform a circumferential load distribution as possible.

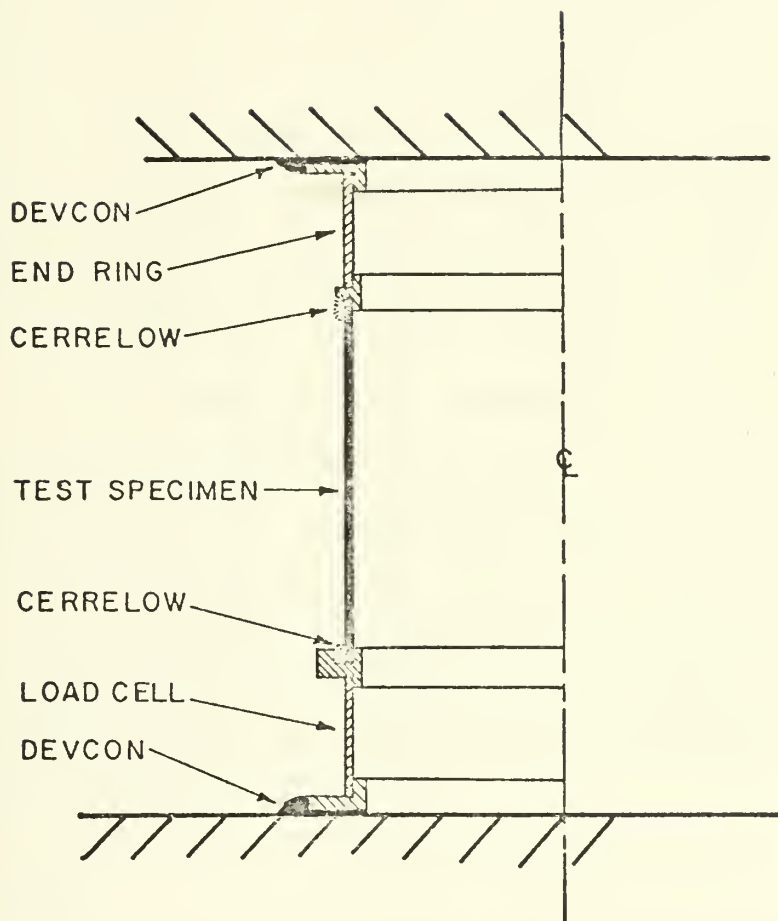
In all versions of SATANS, the boundary conditions are represented by the matrix equation

$$\begin{bmatrix} \Omega \end{bmatrix} \begin{bmatrix} N_s \\ N_s \\ Q_s \\ \phi_s \end{bmatrix} + \begin{bmatrix} \Lambda \end{bmatrix} \begin{bmatrix} U \\ V \\ W \\ M_s \end{bmatrix} = \{ \ell \} \quad (32)$$

Boundary conditions can be specified on  $N_s$  or  $U$ ,  $N_{s\theta}$  or  $V$ ,  $Q_s$  or  $W$ , and  $\phi_s$  or  $M_s$  by prescribing input values for the matrices  $\begin{bmatrix} \Omega \end{bmatrix}$  and  $\begin{bmatrix} \Lambda \end{bmatrix}$ . There is one equation (32) for each boundary of the shell. In their present form, SATANS-I







CYLINDRICAL SHELL TESTING CONFIGURATION

FIGURE II



and SATANS-II assume the column matrix  $\{l\}$  as zero for all harmonics except the axisymmetric harmonic.

As was mentioned earlier, boundary condition discrepancy between mathematical model and physical experiment is cited as a major contributor to thin shell buckling load disagreement. For this reason, three interpretations of Figure 11 were made. The cylinder was represented as experiencing an axisymmetrically applied force  $N_s$  on both ends (condition A), an axisymmetrically applied force  $N_s$  on one end and a meridional deflection restraint on  $U$  at the other (condition B), and an axisymmetric incremental end shortening  $U$  at one end with meridional deflection  $U$  restrained at the other (condition C).<sup>4</sup> These three conditions were investigated on the clamped cylinder, and on a simply supported cylinder for further comparisons and validity checks. Mathematical assignments for boundary conditions A, B and C are shown in Table IV.

## C. ANALYSIS

### 1. Buckling of the Thin Perfectly-Circular Cylinder

A necessary part of this attempt to develop a program for predicting the buckling load of imperfect shells is the establishment of the program's ability to predict the buckling load of perfect shells. Consequently, this section compares the results of a SATANS-II analysis of the thin

---

<sup>4</sup>It is believed that boundary condition C best represents the actual boundary conditions in Figure 11.



TABLE IV

## BOUNDARY CONDITION SPECIFICATIONS

SUPPORT	BOUNDARY CONDITION	BOUNDARY	$N_S$ or $U$	$N_{S\theta}$ or $V$	$Q_S$ or $W$	$\phi_S$ or $M_S$
Clamped	A	Upper	$N_S^{(n)} = -N_O$			
		Lower	$N_S^{(n)} = -N_O$			
	B	Upper	$N_S^{(n)} = -N_O$	$V^{(n)} = 0$	$W^{(n)} = 0$	$\phi_S^{(n)} = 0$
		Lower	$U^{(n)} = 0$			
	C	Upper	$U^{(n)} = U_O$			
		Lower	$U^{(n)} = 0$			
Simple	A	Upper	$N_S^{(n)} = -N_O$			
		Lower	$N_S^{(n)} = -N_O$			
	B	Upper	$N_S^{(n)} = -N_O$	$V^{(n)} = 0$	$W^{(n)} = 0$	$M_S^{(n)} = 0$
		Lower	$U^{(n)} = 0$			
	C	Upper	$U^{(n)} = U_O$			
		Lower	$U^{(n)} = 0$			

Note: When  $N_S^{(n)}$  or  $U^{(n)}$  are specified nonzero, they are set to zero for  $n > 0$ .



cylinder without imperfections with the bifurcation buckling analysis presented by Almroth [Ref. 147]. Almroth's study deals with the influence of edge constraints on the critical load of cylindrical shells of the type used by Arbocz and Babcock. Equation (33) is given by Almroth for the axisymmetric displacement shape of the simply supported cylinder (boundary condition A) prior to buckling.

$$W = r(2\nu\gamma\bar{N}_S + \bar{p})(1 + A_1\sin(a_1s)\sinh(a_1s) + A_2\cos(a_2s)\cosh(a_2s)) \quad (33)$$

where

$$a_1 = \kappa(1 + \bar{N}_S)^{\frac{1}{2}}$$

$$a_2 = \kappa(1 - \bar{N}_S)^{\frac{1}{2}}$$

$$\kappa = (2\gamma)^{-\frac{1}{2}}$$

$$\gamma = h/r/(12(1 - \nu^2))^{\frac{1}{2}}$$

$$\bar{N}_S = -N_S/(2\gamma Eh)$$

$$\bar{p} = (pr)/(Eh)$$





$$A_1 = - \left[ \frac{(\{1 - \bar{N}_S^2\}^{\frac{1}{2}} \sin(\alpha_1) \sinh(\alpha_2) + \bar{N}_S \cos(\alpha_1) \cosh(\alpha_2))}{(1 - \bar{N}_S^2)^{\frac{1}{2}} (\cosh^2(\alpha_2) + \sin^2(\alpha_2))} \right]$$

$$A_2 = - \left[ \frac{(\{1 - \bar{N}_S^2\}^{\frac{1}{2}} \cos(\alpha_1) \cosh(\alpha_2) - \bar{N}_S \sin(\alpha_1) \sinh(\alpha_2))}{(1 - \bar{N}_S^2)^{\frac{1}{2}} (\cosh^2(\alpha_2) - \sin^2(\alpha_2))} \right]$$

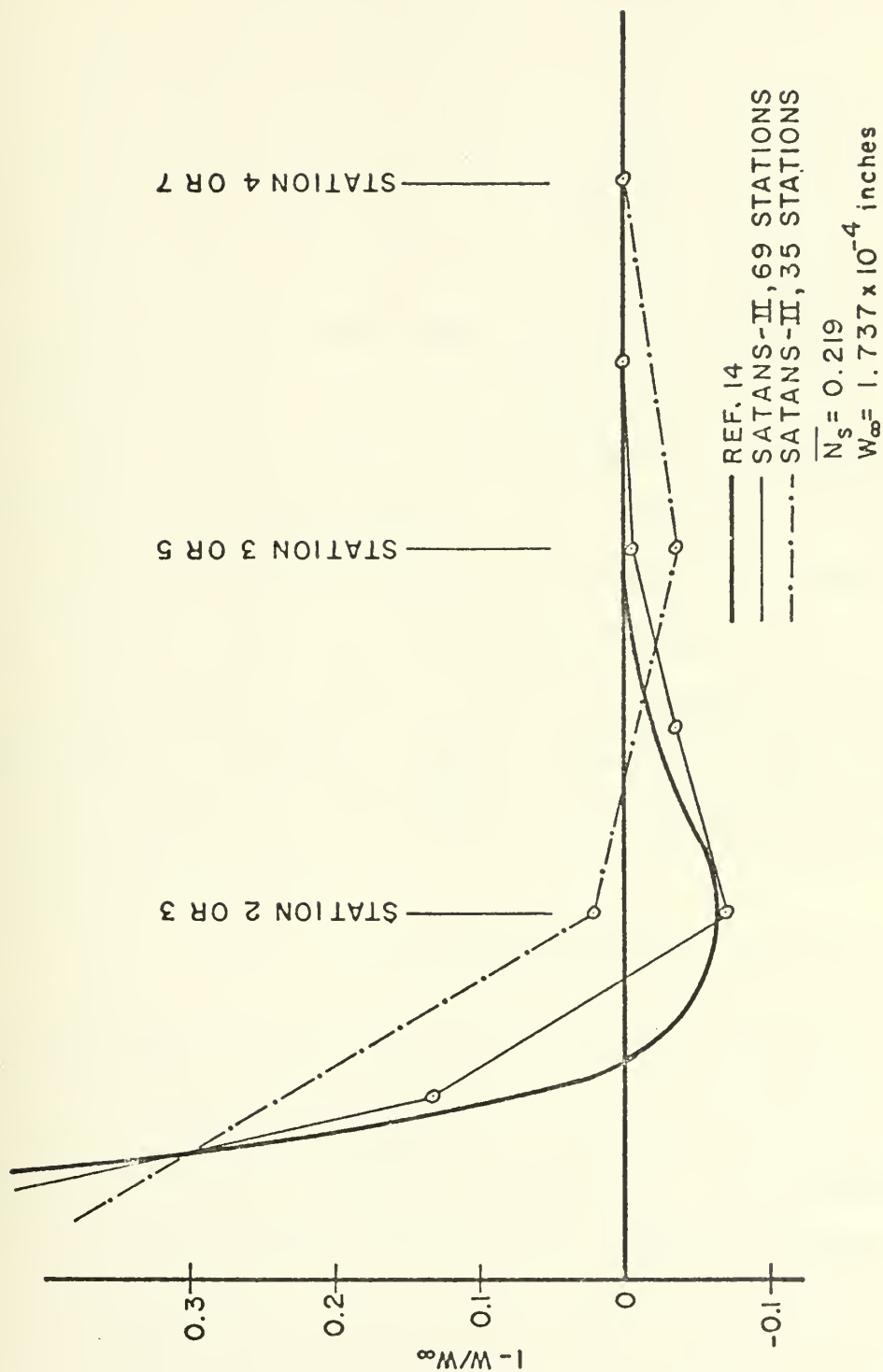
$$\alpha_1 = (a_1 L) / (2r)$$

$$\alpha_2 = (a_2 L) / (2r)$$

and where  $N_s$  is the axial load,  $p$  is a uniform normal pressure,  $h$  is the thickness,  $E$  is Young's Modulus,  $\nu$  is Poisson's ratio,  $L$  is the length and  $r$  is the radius. This solution is referred to as the consistent prebuckling solution, as opposed to the membrane or classical buckling solution where  $W$  is a constant along the meridian. Equation (33) has been solved for shell A-14 and  $W$  is plotted as a function of  $s$  in Figure 12 for an  $\bar{N}_s = 0.21904$ . Also shown in Figure 12 is a plot of  $W$  versus  $s$  obtained from SATANS-II for the same  $\bar{N}_s$  for both 35 and 69 meridional station analyses. Note in Figure 12 that even though only a few stations lie in the boundary zone, the trend is towards the correct solution. The displacement of the 35 station solution, however, is only a rough approximation of the actual state.

Almroth has determined the minimum bifurcation buckling load,  $N_{s_{cr}}$ , and the corresponding value for  $n$  for a





MEMBRANE PREBUCKLE DEFLECTION SHAPE, SHELL A-14

FIGURE 12



range of parameters  $L/r$  and  $r/h$ , using both the consistent prebuckling displacement  $W$  given by equation (33) and the membrane or classical prebuckling solution, where  $W$  is constant, in the Donnell equations. For the simply supported cylinder with an  $r/h$  of the same order of magnitude as shell A-14 and an  $L/r \approx 0.5$ , the critical load is  $\bar{N}_{scr} = 0.863$  ( $N_{scr} = 39.5$  lb/in) with  $n=27$  for the consistent analysis, and  $\bar{N}_{scr} = 1.0$  ( $N_{scr} = 46$  lb/in) with  $n=27$  for the membrane prebuckling analysis. Thus, the consideration of the axisymmetric edge effect, which is analogous to an imperfection, reduces the buckling load by 14.1%. Parametric studies conducted by Almroth show usage of from 100 to 800 meridional stations over the half-length of the shell.

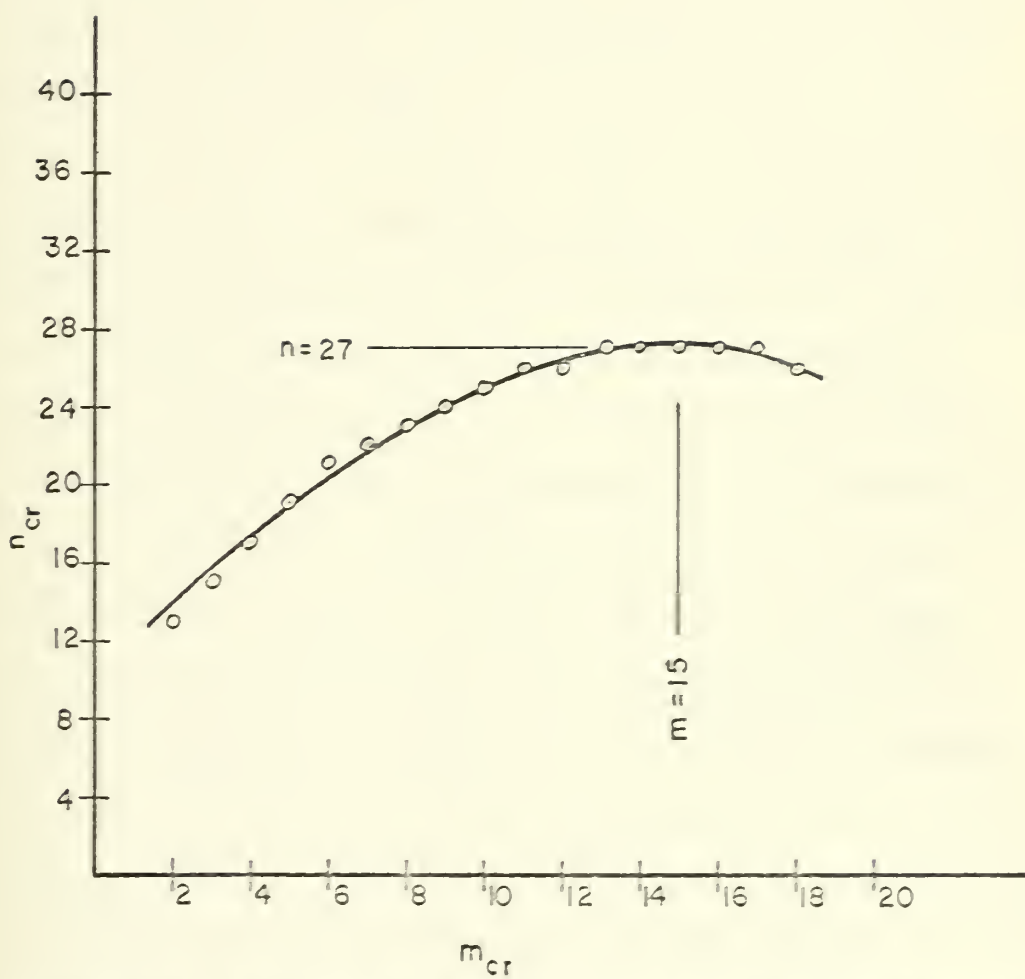
As shown in Ref. 5, use of the membrane prebuckling displacement in Sanders' equations for the simply supported cylinder simplifies the problem to an eigenvalue problem. The buckling mode is

$$W = \delta \sin(m\pi s/L) \cos(n\theta) \quad (34)$$

The equations for the matrix elements in the eigenvalue problem are given in Appendix B. A plot of the critical values of  $m$  and  $n$  is given in Figure 13. The minimum buckling load occurs when  $n=27$  and  $m=15$ , and corresponds to an  $N_{scr}$  of 47.5 lb/in.

SATANS' ability to predict the minimum bifurcation load of a shell for a specified value of  $n$  has been demonstrated by Stilwell [Ref. 15]. SATANS-II analyses of shell





CRITICAL BUCKLING MODES FROM EIGENVALUE  
ANALYSIS, SHELL A-14

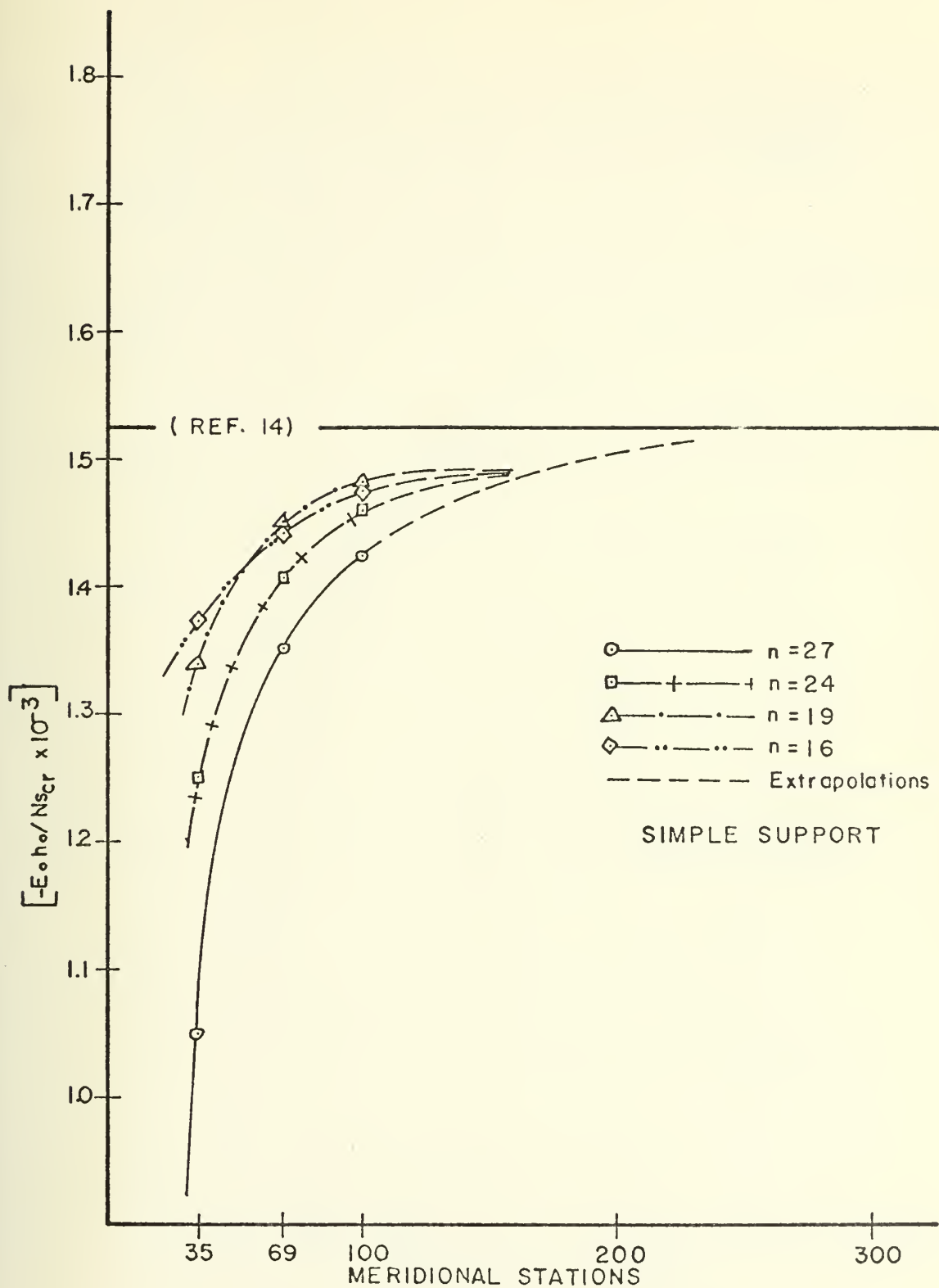
FIGURE 13





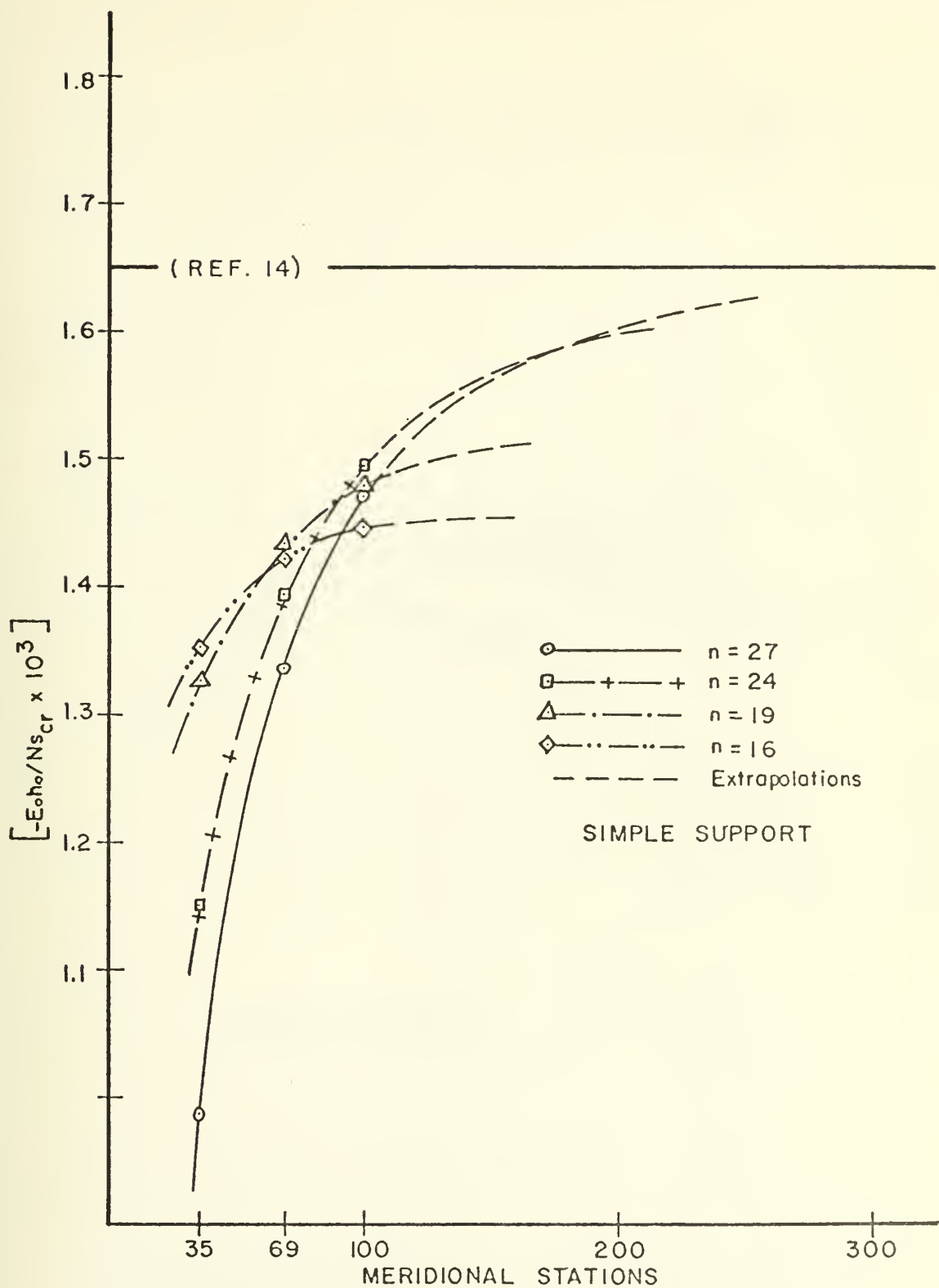
A-14 (simple support, boundary condition A) were conducted over a wide range of  $n$  for both the consistent and membrane prebuckle cases. Figures 14 and 15 give plots of the critical buckling load versus the number of meridional stations for various values of  $n$ . The dashed parts of the curves are estimated extrapolations. It is clear that as the number of stations is increased, SATANS' critical buckling load decreases and the associated harmonic increases. While the  $n=27$  curve predicts the highest buckling load over the range of stations used in both cases, extrapolation of these curves indicates that the  $n=27$  curve would predict the lowest buckling load if the number of stations exceeded 200 to 300. Note that the membrane prebuckle critical buckling curves of Figure 15 seem to flatten much more quickly than for the consistent case. This appears to confirm the occurrence of a reduction in critical buckling load due to the presence of an axisymmetric edge restraint, as noted by Almroth. Figures 16 and 17, which present plots of the critical buckling load versus critical buckling mode of shell A-14 for the 35, 69 and 100 station analyses, also predict this lowering of buckling load due to edge restraint. the 'fanning' of curves in Figure 16 indicate an increase in the number of meridional stations will produce a lesser buckling load decrease than in Figure 17. These figures also predict a lower critical buckling load and a higher critical buckling mode with increasing meridional stations.





BUCKLING LOAD vs STATIONS  
 MEMBRANE PREBUCKLE ANALYSIS, SHELL A-14  
 FIGURE 14

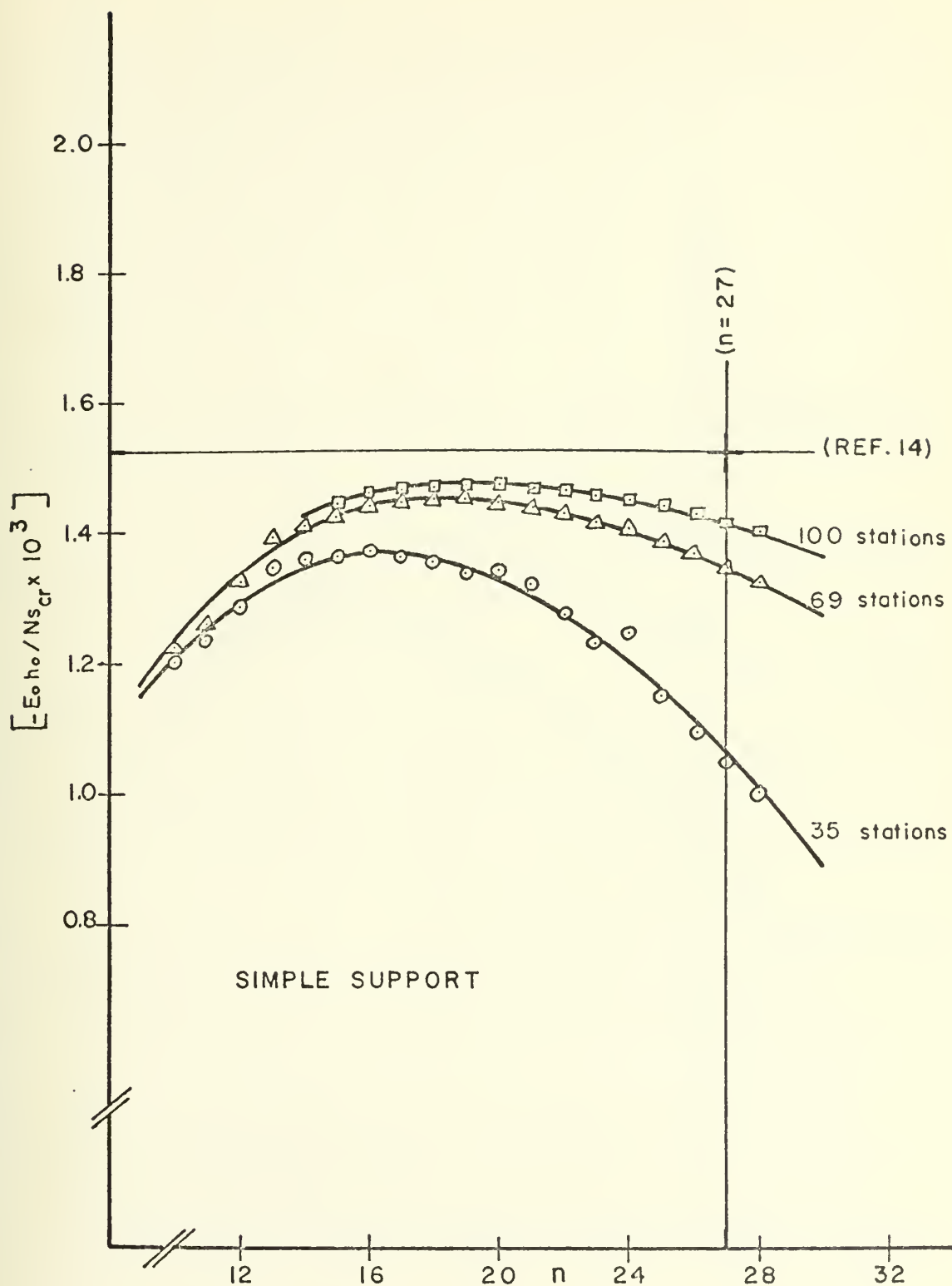




BUCKLING LOAD vs STATIONS  
CONSISTENT ANALYSIS, SHELL A-14

FIGURE 15



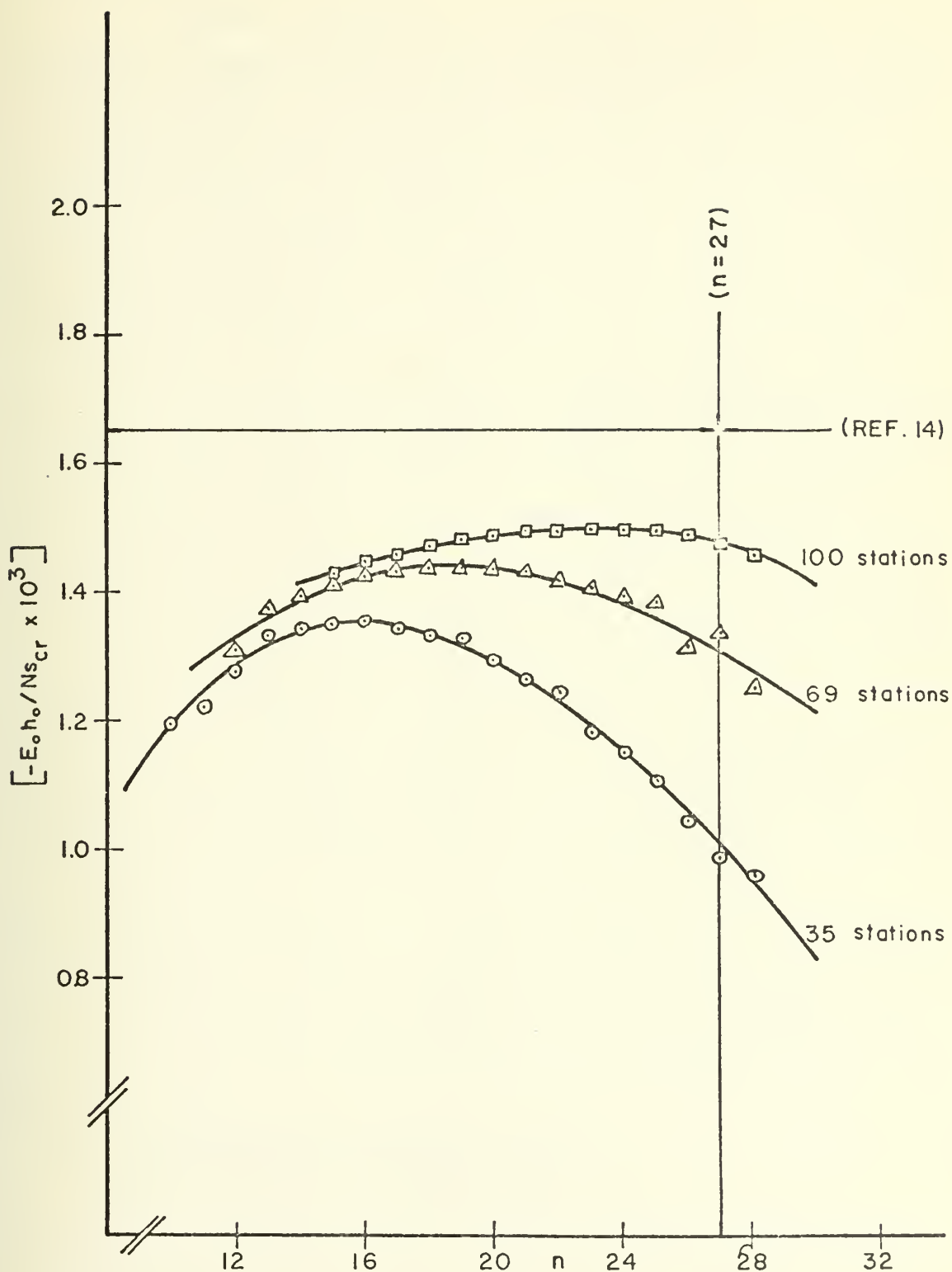


BUCKLING LOAD vs BUCKLING MODE  
MEMBRANE PREBUCKLE ANALYSIS, SHELL A-14

FIGURE 16







BUCKLING LOAD vs BUCKLING MODE  
CONSISTENT ANALYSIS, SHELL A-14

FIGURE 17

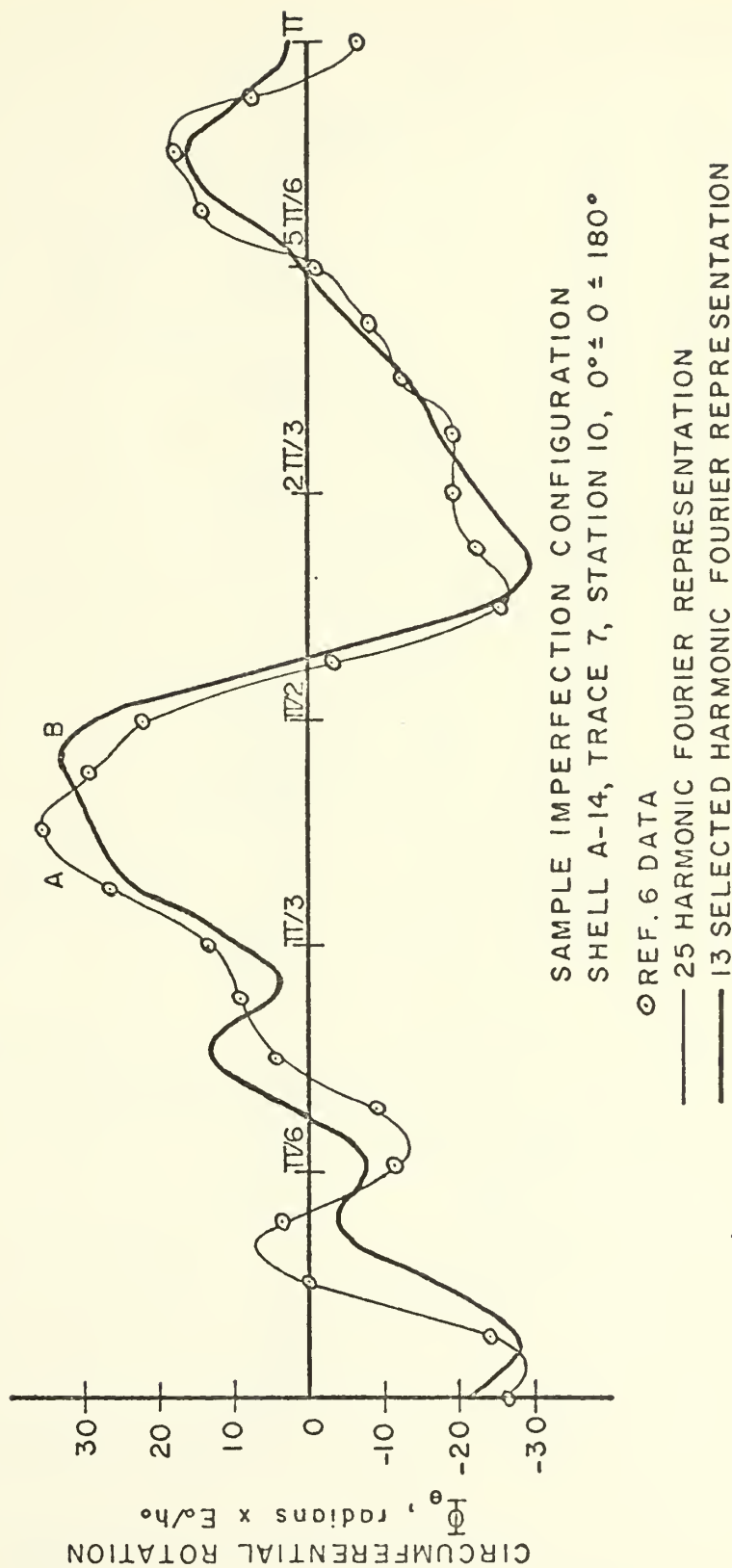


Figures 14 through 17 indicate that, given enough stations, SATANS-II can predict a critical buckling load and mode for the thin-walled shell that agrees with Almroth's prediction. However, for the 35-station analysis, which is the analysis to be used for the imperfect shells, the critical load of 51.1 lb/in and harmonic of 16 are significantly different from the correct values. As a result of the coarse mesh used by SATANS-II in the following analysis, the critical buckling loads for the imperfect shells will be higher than the experimental values. Nevertheless, it will be shown that the introduction of a totally arbitrary, naturally-occurring imperfection pattern on the imperfection-free mathematical model of shell A-14 results in a significant reduction in critical buckling load. This is not only sufficient to demonstrate the capability of the program to perform the analyses, but it also provides an estimate of the degree of imperfection sensitivity of the shell. It will be shown that application of this estimate of sensitivity to Almroth's buckling load provides an accurate prediction of the buckling load of the imperfect shell.

## 2. Introduction of Imperfections

When prepared as indicated in section V.A.2, the imperfection rotation Fourier coefficients are in a form for direct introduction into SATANS-II. Figure 18 shows the applicability of the periodogram method of expansion of the imperfection data according to equations (29) and (30).

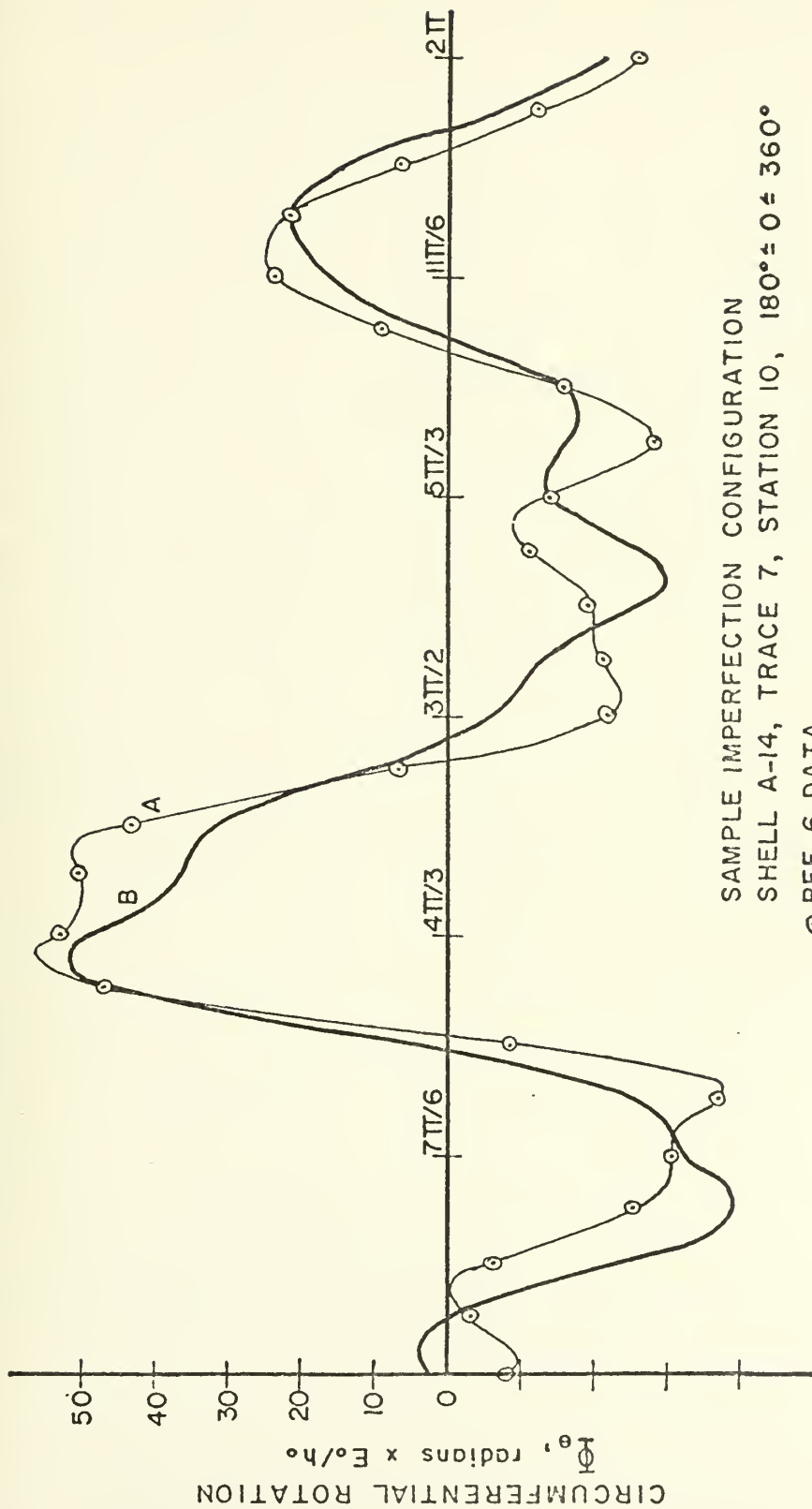




CIRCUMFERENTIAL IMPERFECTION ROTATION REPRESENTATIONS -  $\Phi_\theta$  vs  $\theta$

FIGURE 18 - PLATE 1 OF 2





SAMPLE IMPERFECTION CONFIGURATION  
 SHELL A-14, TRACE 7, STATION 10,  $180^\circ \pm 0 \pm 360^\circ$   
 ○ REF. 6 DATA  
 — 25 HARMONIC FOURIER REPRESENTATION  
 — 13 SELECTED HARMONIC FOURIER REPRESENTATION

CIRCUMFERENTIAL IMPERFECTION ROTATION REPRESENTATION -  $\Phi_\theta$  vs  $\theta$

FIGURE 18 PLATE 2 OF 2





Curve A is the graph of a solution of equation (30) representing the circumferential imperfection rotation at station 10 plotted against  $\theta$ . It is seen to pass smoothly through all the data points.

Only the zeroeth harmonic ( $n=0$ ) and twelve others can be accommodated by SATANS-II. In the case where the shell response and the imperfection are limited to a few major harmonics, all important harmonics can be included in the analysis. For example, the  $\lambda=6$  shallow spherical cap has only the  $n=2$  harmonic as the major harmonic of response, and the imperfection curves of Figure 8 require only a few Fourier harmonics for adequately accurate representation. Also, the few required harmonics for imperfection representation are in the vicinity of the  $n=2$  harmonic. This problem is well within the limits of SATANS-II.

The thin-walled cylinder, however, responds in a large number of harmonics. This can be seen in Figure 16 -- many harmonics produce critical buckling loads close to the value of the minimum critical buckling load. Additionally, the imperfection requires many harmonics. Thus, as mentioned in section V.A.4, a difficult selection of harmonics for use in the analysis must be made. Six harmonics were selected on the basis of the shell response and six harmonics were selected on the basis of the imperfection characteristics. Of course, all 13 selected harmonics will contain both the imperfection characteristics and the shell response characteristics.



For the shell response harmonic selection, the critical buckling loads of shell A-14 for specified values of  $n$ , discussed in the previous section, are presented in Table V. Values were assigned to each harmonic according to the legend of Table V and six were selected based on these assignments.

For the imperfection harmonic selection, the sums of the absolute values of the Fourier coefficients for both sine and cosine terms of both meridional and circumferential imperfection rotations were tabulated and are presented in Table VI. Values were again assigned to each harmonic according to the legend of Table V, and six additional harmonics were selected.

The complete harmonic selection process for shell A-14 was accomplished by a comparison of the values assigned to each harmonic for both the imperfection and the shell. Table VII presents this comparison along with the actual harmonics selected for the analysis. Note that no overlap of important harmonics occurred, as the imperfection required harmonics seven and below and the shell required harmonics ten and above. The harmonics used with shell A-13 were  $n=0$  and  $n=2,3,4,6,8,9$  for the imperfection and  $n=10,11,12,13,14,15$  for the shell response with a simple support, and  $n=13,14,15,16,17,18$  for the shell response with a fixed support.

Once the specific harmonics for inclusion in the analysis are determined, the appropriate  $\bar{\Phi}_S$  and  $\bar{\Phi}_\theta$



TABLE V  
CRITICAL BUCKLING LOADS OF INDIVIDUAL HARMONICS

HARMONIC	FIXED SUPPORT			SIMPLE SUPPORT		
	BUCKLING LOAD $\times P_0$	$P/P_{cr}$	ASSIGNED VALUE	BUCKLING LOAD $\times P_0$	$P/P_{cr}$	ASSIGNED VALUE
2	6+			6+		
3	6+			6+		
4	5.320			6+		
5	5.120			5.720		
6	4.250			4.080		
7	2.415	2.380		2.445	2.390	
8	1.611	1.550		1.661	1.630	
9	1.221	1.180	-	1.291	1.260	
10	1.093	1.050	*	1.157	1.130	-
11	1.088	1.050	*	1.131	1.110	-
12	1.069	1.030	*	1.085	1.060	+
13	1.038	1.000	**	1.037	1.014	*
14	1.043	1.010	*	1.029	1.006	*
15	1.054	1.020	*	1.026	1.004	*
16	1.058	1.020	*	1.022	1.000	**
17	1.074	1.030	*	1.030	1.008	*
18	1.083	1.040	*	1.037	1.015	*
19	1.120	1.080	+	1.040	1.018	*
20	1.200	1.160	-	1.069	1.050	+
21	1.240	1.190	-	1.090	1.070	+
22	1.320	1.270		1.130	1.110	-
23	1.340	1.290		1.168	1.144	-
24	1.344	1.290		1.200	1.170	-

Notes: 1.  $P_0 = 50$  psi.

2. The trigger in each harmonic is an internal pressure of  $10^{-7}$  psi.

3. Each analysis included the indicated harmonic plus  $n=0$ .

4. Value assignments are according to the following legend:

SYMBOL	VALUE
**	absolutely necessary
*	great
+	moderate
-	slight
	none



TABLE VI

RELATIVE IMPERFECTION ROTATION COEFFICIENT SIZES, SHELL A-14

HARMONIC	$\Phi_s$				$\Phi_\theta$			
	COS	VALUE	SIN	VALUE	COS	VALUE	SIN	VALUE
0	5.32	*	0.00		0.01		0.00	
1	3.18	*	2.03	*	0.34		0.40	
2	4.85	*	9.08	*	9.46	*	13.26	*
3	1.50	+	7.34	*	13.46	*	3.11	+
4	2.80	*	1.74	+	6.28	+	28.54	*
5	1.71	+	0.79		7.84	+	9.98	*
6	1.33	+	1.48	+	5.20	+	4.07	+
7	0.56		1.85	+	11.20	*	6.26	+
8	0.57		0.86	-	7.88	+	1.92	-
9	0.46		0.69		3.75	-	2.88	-
10	1.10	+	0.85	-	5.60	+	5.99	-
11	0.77		0.91	-	2.17	-	1.68	-
12	1.39	+	1.67	+	5.73	+	6.77	+
13	1.05	+	1.01	+	2.98	-	3.38	+
14	0.77		0.83	-	2.60	-	1.55	+
15	0.91	-	0.46		1.05	-	1.26	-
16	1.09	+	0.69		0.73		2.17	-
17	0.54		1.15	+	1.31	-	1.17	-
18	0.83	-	1.03	+	1.16	-	1.46	-
19	0.94	-	0.78		0.48		1.04	-
20	0.41		0.81	-	0.49		0.48	
21	0.42		0.68		0.45		0.19	
22	0.43		0.63		0.31		0.15	
23	0.68		0.58		0.11		0.10	
24	0.32		0.01		0.01		0.01	

- Notes: 1. Numbers represent the sums of the absolute values of the imperfection rotation coefficients over the entire shell.
2. Value assignments were made according to the legend of Table V.





TABLE VII  
HARMONIC SELECTION, SHELL A-14

H A R M O N I C	$\bar{\Phi}_S$ COEFFI- CIENT		$\bar{\Phi}_\theta$ COEFFI- CIENT		SHELL RESPONSE		SELECTED HARMONICS		
	COS	SIN	COS	SIN	FIXED SUPPORT	SIMPLE SUPPORT	FIXED SUPPORT		SIMPLE SUPPORT
							PRIMARY	ALTER- NATE	
0	*						X	X	X
1	*	*					X	X	X
2	*	*	*	*			X	X	X
3	+	*	*	+			X	X	X
4	*	+	+	*			X	X	X
5	+		+	*			X	X	X
6	+	+	+	+					
7		+	*	+			X	X	X
8		-	+	-					
9			-	-	-				
10	+	-	+	+	*	-	X		
11		-	-	-	*	-	X		
12	+	+	+	+	*	+	X	X	
13	+	+	-	+	**	*	X	X	X
14		-	-	-	*	*	X	X	X
15	-		-	-	*	*	X	X	X
16	+		-	-	*	**		X	X
17		+	-	-	*	*		X	X
18	-	+	-	-	*	*			X
19	-			-	+	*			
20		-			-	+			
21					-	+			
22						-			
23						-			
24						-			

- Notes: 1. Harmonic zero is required by SATANS-II.
2. Value assignments are taken from Tables V and VI.
3. 'X' indicates a selected harmonic.



coefficients (obtained from the periodogram) must be loaded into the SATANS-II arrays PHIXB and PHITB (performed in subroutine IMPERF) in the following order:

1. The first KMAX locations contain the  $\bar{\phi}_s$ 's (or  $\bar{\phi}_\theta$ 's) of mode 0.
2. The second KMAX locations contain the  $\bar{\phi}_s$ 's (or  $\bar{\phi}_\theta$ 's) of mode -i.
3. The third KMAX locations contain the  $\bar{\phi}_s$ 's (or  $\bar{\phi}_\theta$ 's) of mode +i.
4. The fourth KMAX locations contain the  $\bar{\phi}_s$ 's (or  $\bar{\phi}_\theta$ 's) of mode -j.
5. Et cetera, until all modes are entered.

KMAX is the FORTRAN name for the number of meridional stations to be included in the analysis. One special case must be considered where the shell has an initial or a final pole. In this case, rotations are zero in all but the n=1 harmonic. If this harmonic is included in the analysis, the imperfection rotation coefficients at the first (or last) station should all be set to zero except for the coefficients in the n=1 harmonic. In the case of an initial pole, the coefficient associated with the -1 index should be placed in the first location of the second set of KMAX locations in arrays PHIXB and PHITB, and the coefficient associated with the +1 index should be placed in the first location of the third set of KMAX locations. For a final pole, the coefficient associated with the -1 index should be placed in the first location of the next to last set of KMAX



locations, and the coefficient associated with the +1 index should be placed in the first location of the last set of KMAX locations.

To illustrate the effect of the selection of harmonics on the imperfections, equation (30) was solved using only the 13 selected harmonics. The resulting circumferential imperfection rotation representation at station 10 appears as curve B in Figure 18. To determine the effect of the inability to include all nine harmonics deemed important to the shell response with a fixed support, an alternate selection of harmonics was made for this case (see Table VII). A complete SATANS-II analysis was performed with this alternate selection and the results were found to differ from those using the primary harmonic selection by approximately 2%.

### 3. Results

Six analyses (boundary conditions A, B and C with clamped and simple supports) were made for each shell where the imperfections were reduced by a factor of 1000. These 'minute' imperfections acted only as triggers for the modal deflections and the resulting solutions gave the shell's consistent critical bifurcation buckling loads. These results are presented in Table VIII under the category of minute imperfections. Selected cases were analyzed where the minute imperfection triggers were replaced by a  $10^{-7}$  psi internal pressure trigger and the results were identical.



TABLE VIII

BUCKLING LOADS, MINUTE VERSUS FULL IMPERFECTIONS

SUPPORT	DEGREE OF IMPERFECTION	BOUNDARY CONDITION	SHELL A-14		SHELL A-13	
			BUCKLING LOAD (lb/in)	REDUCTION (%)	BUCKLING LOAD (lb/in)	REDUCTION (%)
CLAMPED	Minute	A	47.20		35.60	
		B	51.90		50.60	
		C	56.00		55.10	
	Full	A	43.00	8.90	*	-
		B	46.60	10.20	40.70	19.55
		C	49.00	12.50	40.15	22.70
SIMPLE	Minute	A	48.00		46.60	
		B	51.10		50.60	
		C	54.10		55.30	
	Full	A	42.80	10.8	34.30	26.30
		B	46.10	9.8	38.00	24.90
		C	47.90	11.5	42.7	22.80

\* insufficient data.

The same six analyses for each shell were also made using the full imperfections. Results for the final load at which a converged solution could be obtained are also shown in Table VIII along with the percent reduction in the buckling load for each case.

Since the full imperfection is introduced at the first load step as a pseudo load, the program requires considerably more iterations than normal to obtain the first



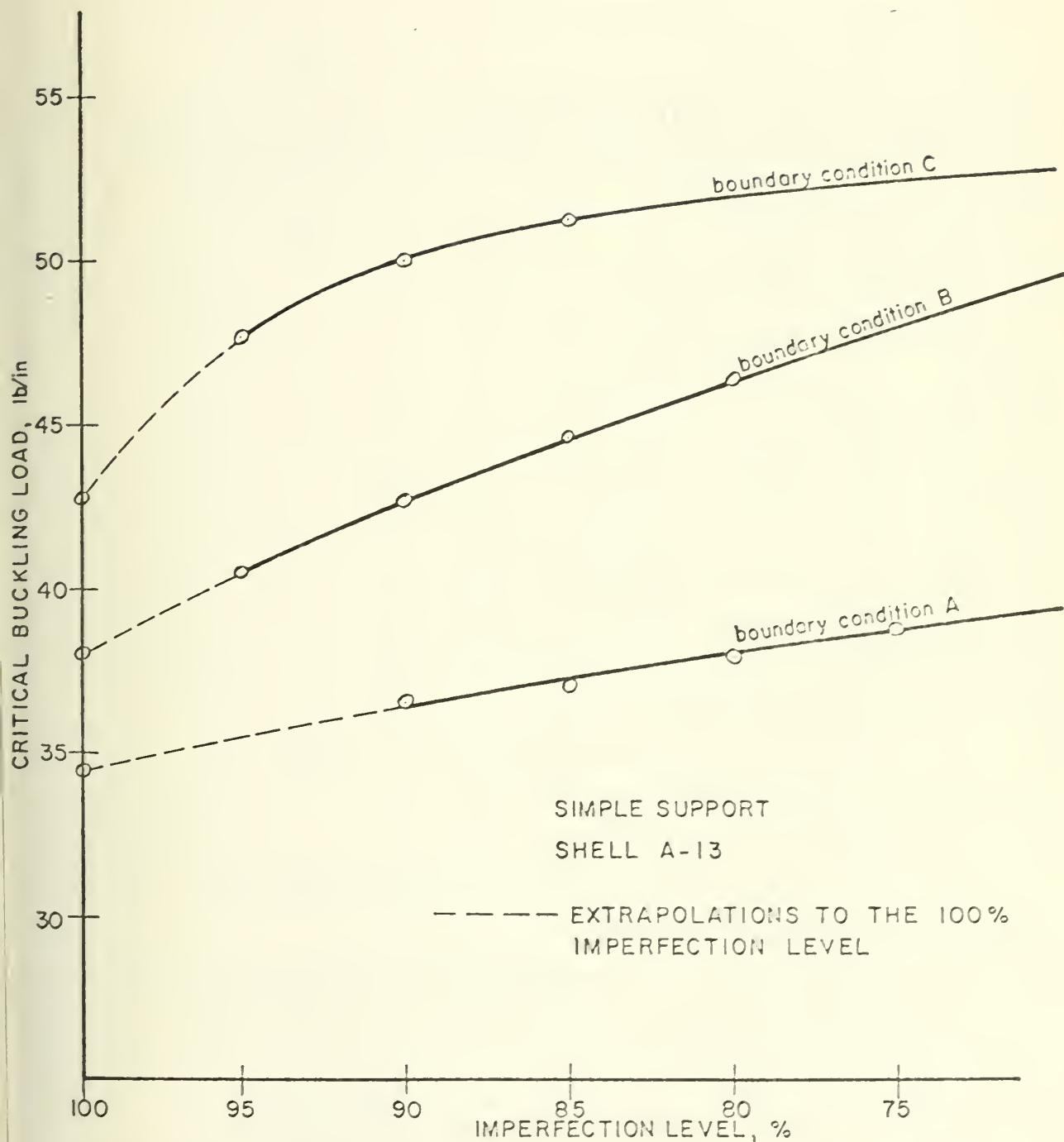


solution. The subsequent solution usually proceeds in a completely normal fashion. However, convergence difficulties may be encountered in cases where the imperfection level is high. This was the case with shell A-13, as some of its imperfection deviations exceeded  $3\frac{1}{2}$  shell wall thicknesses, and fluctuated over 6 thicknesses in a  $\theta$  arc of only  $53^\circ$ . For shell A-13, a 70% initial imperfection level was the maximum for which a converged solution could be obtained on the first load step. Consequently, buckling loads were computed with a maximum of 80%, 85%, 90% and 95% of the full imperfection data. For the 80% imperfection, 70% was introduced at load step one and 10% was added at load step two. For the three other solutions, 5% increments were added at various load steps. Since SATANS uses the total value of the variables and not the incremental values, each intermediate solution is correct for its given load and imperfection level, but the load-deflection characteristics are invalid. An imperfection level of 95% was the absolute maximum for which a converged solution could be obtained for for shell A-13, and a short 5% extrapolation was made to obtain the data presented in Table VIII for this shell.<sup>5</sup> This procedure is illustrated for the shell with a simple support in Figure 19. A comparison of load steps and iterations for both shells under these conditions is presented in Table IX.

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<sup>5</sup>For shell A-13 with clamped boundary condition A, a converged solution was not obtained for an imperfection level above 85%. This condition is therefore not included in the results. A similar problem was encountered by Dantone [Ref. 57] with this boundary condition.





CRITICAL BUCKLING LOAD vs IMPERFECTION LEVEL

FIGURE 19



TABLE IX  
LOAD STEPS VERSUS ITERATIONS

SHELL A-14			SHELL A-13			
LOAD STEP	INCREMENTAL IMPERFECTION ADDITION	ITERATIONS REQUIRED	LOAD STEP	INCREMENTAL IMPERFECTION ADDITION	ITERATIONS REQUIRED	
1	100%	7	1	70%	24	
2		2	2	10%	6	
3		2	3	5%	16	
4		3	4		12	
5		3	5		9	
6		3	6		3	
7		3	7		8	
8		3	8		6	
9		3	9	5%	19	
10		3	10		3	
11		3	11	5%	60	
12		4	12		58	
13		4	13		18	
14		4	14		16	
15		5	15		16	
16		7	16		12	
17		10		1 <sup>st</sup> load step size reduction		
18		16		17		4
1 <sup>st</sup> load step size reduction			2 <sup>nd</sup> load step size reduction			
19		3	18		3	
20		2	19		2	
2 <sup>nd</sup> load step size reduction			3 <sup>rd</sup> load step size reduction			
21		3	termination			
3 <sup>rd</sup> load step size reduction			(P <sub>Cr</sub> =40.6 lb/in)			
22		2				
termination						
(P <sub>Cr</sub> =46.0 lb/in)						

Note: This data corresponds to boundary condition B, simple support.



#### D. DISCUSSION

The SATANS-II investigation of the buckling load of the perfect cylinder (discussed in section V.C.1) indicates that a numerical analysis using 35 stations results in a higher predicted buckling load than the correct analytical buckling load. Consequently, the SATANS-II results for the prediction of the critical buckling load of the imperfect cylinder are expected to be high. Table X compares the results of the SATANS-II analysis (column A) with the actual experimental results of Ref. 6 (column E) and shows this to be the case. The use of more stations to lower the predicted buckling load can be accomplished only by either decreasing the number of harmonics considered in the analysis or by increasing overall program size. Both of these choices are impractical at the present time since the number of harmonics already in the analysis appears to be low considering the number required for shell response and the imperfection data, and the present program core storage requirement is large.

It is possible, however, to apply the SATANS-II results for the percent reduction in the buckling load due to the imperfections (see Table VIII and Column B, Table X) to a more accurate buckling load of the perfect shell from an analysis like that of Almroth to get a more accurate estimate of the buckling load of the imperfect shell. When the percent reduction from the consistent minute imperfection buckling load to the consistent full imperfection buckling





load, determined by SATANS-II, is applied to the accurate consistent bifurcation buckling load of Almroth (column C, Table X), the result is a prediction of the actual buckling load of the imperfect shell. These imperfect shell predicted buckling loads are shown in column D of Table X and are seen to be very close to the actual buckling loads of the imperfect shells, given in Column E of Table X.

The percent reductions in buckling loads determined by SATANS-II are considered to be applicable to the accurate consistent bifurcation buckling loads of Almroth since the imperfection characteristics are seen to be concentrated in the lower ten harmonics (see Table VI), where shell response does not appear to be largely affected by the number of meridional stations in the analysis (see Figures 14 and 15).

#### E. PROPOSED ANALYSIS PROCEDURE

When the SATANS-II predicted buckling load of the perfect shell is higher than the analytical prediction, as is the case with the extremely thin-walled cylinder, the following procedure is proposed.

1. Determine the consistent bifurcation buckling load as close as possible.
2. Determine the buckling load with SATANS-II using minute imperfections.
3. Determine the buckling load with SATANS-II using full imperfections and compute the percent reduction from step 2.
4. Apply this reduction to the buckling load of step 1.



TABLE X  
PREDICTED BUCKLING LOADS OF THE IMPERFECT SHELL

	A	B	C	D	E
BOUNDARY CONDITION	SATANS-II PREDICTIONS WITH FULL IMPERFECTIONS (lb/in)	SATANS-II PERCENT REDUCTION (%)	ALMROTH'S ANALYTICAL CONSISTENT PREDICTION /Ref. 14/ (lb/in)	PERCENT REDUCTION APPLIED TO ANALYTICAL PREDICTION (lb/in)	ACTUAL EXPERIMENTAL RESULTS /Ref. 6/ (lb/in)
SHELL A-14	43.00	8.9	42.5	38.70	35.4
CLAMPED	49.00	12.5	42.0	36.75	
SHELL A-13	40.15	27.2	42.0	30.50	31.4
CLAMPED					



This procedure is expected to work only when the result of step 2 is reasonably close to that of step 1.



## VI. CONCLUSIONS

### A. SATANS-I

The computer program SATANS-I has been constructed from SATANS. It is a more user-oriented version of the program by Ball, whose primary modification is the introduction of an equipment-independent graphical output ability.

### B. SATANS-II

SATANS-II is a further modification of SATANS where the restriction that all applied loading and initial conditions be symmetrical about some meridional plane has been removed. In addition, SATANS-II possesses the capability of including experimentally-determined naturally-occurring imperfections or malformations induced during fabrication, mathematically described imperfections of any type, frequency or location, or graphically described imperfections due to damage suffered after fabrication. The imperfections are introduced into SATANS-II by using the imperfection deviations along discrete circumferences to determine the associated meridional and circumferential imperfection rotations at the mesh points, performing a Fourier expansion on these rotations and then use of the Fourier coefficients. In cases where the important shell response harmonics and the harmonics required for imperfection representation exceed the limits of SATANS-II, a selection must be made.





Instructions for the use of both SATANS-I and SATANS-II are contained in Appendix C and complete listings of both programs are given in other appendices. SATANS-I requires 210 k-bytes (53k words) of core on an IBM-360/67 computer using 'single precision,' while SATANS-II requires 426 k-bytes (107k words) of core. Imperfect shell analyses performed by SATANS-II in this report used a 35 station meridian and 25 circumferential modes. Execution times were an average of 60 minutes, although execution times of between 15 and 30 minutes can be expected for analyses using 15 or less modes.

### C. IMPERFECT SHELLS

SATANS-II has demonstrated an ability to perform a numerical structural analysis on the arbitrarily imperfect shell of revolution. Imperfections of over three shell wall thicknesses in depth have been handled. Increasing solution difficulty relates directly to increasing imperfection complexity and increasing shell instability. In those cases where extremely thin-walled shells result in perfect (imperfection-free) buckling loads from SATANS that are higher than analytically determined buckling loads, a procedure has been devised where the percent reduction due to the introduction of full imperfections can be applied to the analytically determined buckling load, and an imperfect shell buckling load predicted. These predictions have been shown to be very close to the actual imperfect shell buckling loads for the two specific axially loaded cylinders considered.



## ADDENDUM

### A DIGITAL COMPUTER STUDY OF THE EFFECTS OF VARIOUS ARTIFICIAL BOUNDARY CONDITIONS AT THE POLE OF A SHALLOW SPHERICAL SHELL

#### I. INTRODUCTION

The design of many shell of revolution structures requires continuity of the structure at one or both poles. At such a pole, the radius becomes zero and special conditions must be imposed on the deflections and the stress resultants to assure finite strains and equilibrium. As a consequence of the difficulty of incorporating these conditions into a structural analysis computer program, many researchers model such a structure as having a small hole or a small rigid plug at the pole. This addendum investigates the applicability of the various artificial pole conditions by examining their effect on the stability of a clamped spherical cap subjected to axisymmetric and asymmetric pressure loads.

Various polar artificialities are discussed and the boundary equations associated with their use are given, as are those for the continuous pole. A determination of the applicability of the various poles is made by comparisons of their effect on the shell buckling loads and by comparing the errors in the normal displacement and meridional membrane force distributions incurred by their use.



The computer program SATANS, developed by Ball [Ref. 3], was used to conduct this study and selected results of the SATANS analyses are checked for validity with the computer programs BOSOR [Ref. 15] and STAGS [Ref. 15]. SATANS has a special routine that incorporates the proper conditions to be enforced at a pole. BOSOR also has this special ability but STAGS is not yet so equipped.<sup>6</sup>

SATANS, a one-dimensional finite difference equilibrium formulation based on Sanders' equations, was run on an IBM-360/67 computer under OS/MVT. BOSOR, a one-dimensional finite difference energy formulation based on the Donnell equations, was run on a UNIVAC-1108 computer under EXEC-VIII, while STAGS, a two-dimensional finite difference energy formulation was run on a CDC-6600 computer under COMPASS-12.

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<sup>6</sup>As of February, 1972.



## II. STATEMENT OF THE PROBLEM

### A. GEOMETRY AND LOADING

The structure investigated is the clamped shallow spherical cap whose geometry can be specified by the single nondimensional parameter  $\lambda$ , where

$$\lambda = 2(3(1-\nu^2))^{\frac{1}{4}}(H/h)^{\frac{1}{2}} \quad (\text{AD-1})$$

and where  $H$  is the rise of the shell and  $h$  is its thickness. For this study, Poisson's ratio was taken as 0.3, Young's modulus as  $30 \times 10^6$  psi and  $h$  as 1.0 inches. Shells of  $\lambda = 6$  and  $\lambda = 18$  were investigated however only the results of the  $\lambda = 6$  shell are given in detail.

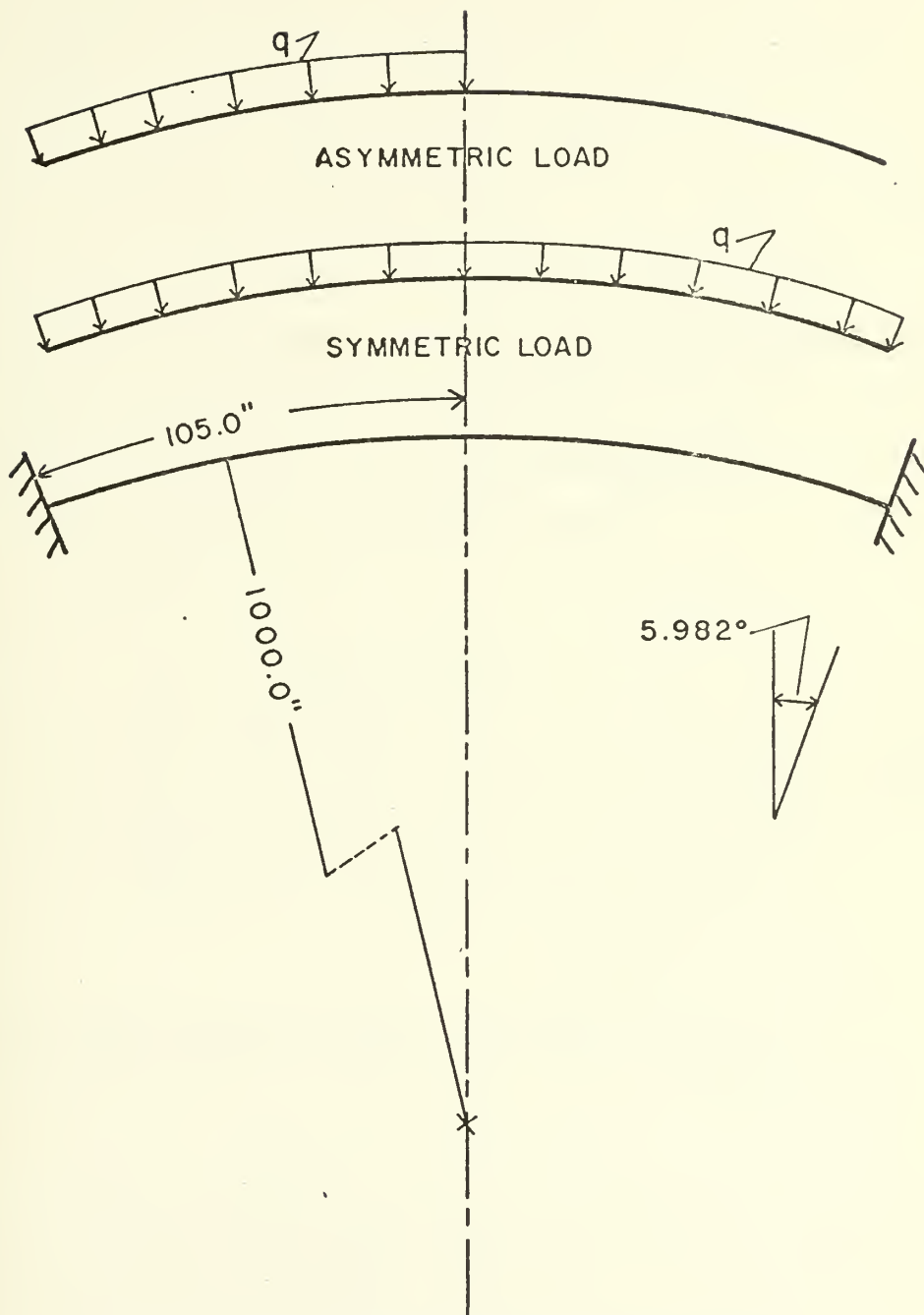
The classical buckling pressure of a complete sphere is given as  $q_0$ , where

$$q_0 = 2Eh^2/R_s / (3(1-\nu^2))^{\frac{1}{2}} \quad (\text{AD-2})$$

and where  $R_s$  is the radius of curvature. For this study, two loading conditions were used. The cap was subjected to a uniform normal pressure (symmetrical load) and a uniform normal pressure over half the cap (asymmetrical load). These loadings are shown in Figure 20. In each case, the magnitude of the applied pressure is  $q$  and the buckling results are presented as the ratio  $q/q_0$ .







$\lambda = 6$  SHALLOW SPHERICAL CAP  
GEOMETRY AND LOADING

FIGURE 20



## B. POLE CONDITIONS

A shell is considered to have a pole if the structure is continuous through its axis of revolution. At a pole, the radius is zero and special conditions must be imposed on deflections  $u$ ,  $v$  and  $w$ , and on the meridional moment  $m_s$  to assure finite strains and equilibrium. The computer program SATANS is equipped with the capability to impose these special boundary conditions. A full derivation of the required conditions is given in Appendix D of Ref. 3. The results of that derivation are presented below.

For the zeroeth Fourier harmonic ( $n=0$ ):

$$\begin{aligned}u &= v = m_{s\theta} = t_{s\theta} = 0 \\w' &= m_s' = 0 \\m_{s\theta} &= m_s \\t_\theta &= t_s = b(1-\nu) (u' + \omega_s w + \frac{1}{2}\beta_s) - t_T\end{aligned}\tag{AD-3}$$

For the first Fourier harmonic ( $n=1$ ):

$$\begin{aligned}(u \pm v) &= w = u' = 0 \\m_s &= m_\theta = m_{s\theta} = 0 \\t_s &= t_\theta = t_{s\theta} = 0\end{aligned}\tag{AD-4}$$

When a double sign ( $\pm$ ) appears, the upper sign applies for an initial pole and the lower sign applies for a final pole.



For the second harmonic ( $n=2$ ):

$$\begin{aligned}
 u &= v = w = m_s' = 0 \\
 t_\theta &= -t_s = \pm t_{s\theta} \\
 m_\theta &= -m_s = \pm m_{s\theta} \\
 t_s &= b(1-v) (u' + \frac{1}{2}\beta_s)
 \end{aligned}
 \tag{AD-5}$$

For all higher harmonics ( $n>2$ ):

$$\begin{aligned}
 u &= v = w = 0 \\
 m_s &= m_\theta = m_{s\theta} = 0 \\
 t_s &= t_\theta = t_{s\theta} = 0
 \end{aligned}
 \tag{AD-6}$$

For rotations at the pole, for the first harmonic ( $n=1$ ):

$$\begin{aligned}
 \phi_s &= -w' + \omega_s u \\
 \phi_\theta &= -\phi_s \\
 \phi &= \frac{1}{2}(2v' \pm u')
 \end{aligned}
 \tag{AD-7}$$

and for all other harmonics,

$$\begin{aligned}
 \phi_s &= \phi_\theta = 0 \\
 \phi &= \frac{1}{2}(2v' \pm nu')
 \end{aligned}
 \tag{AD-8}$$

Numerous artificial boundary conditions can be substituted for the correct conditions at the pole. For example,



a small hole can be placed at the pole and can exist with the boundary completely free, or have conditions imposed such that the meridional rotation  $\phi_s$  and deflection  $u$  are restrained. A meridional line load  $N_s$  of magnitude sufficient to replace that 'lost' due to the hole can be applied. Another artificial pole condition is that best described as a small rigid plug. Here, both the meridional as well as the circumferential deflection is restrained along with the meridional rotation. A normal line load  $-P$  whose total equals that loading 'lost' due to the hole or plug can be applied at the boundary of the hole or plug.

Preliminary numerical studies showed that the line loadings effected a noticeable change in the solution only in the immediate area of the boundary, hence, the line loads were not considered further. Preliminary studies also showed that the cap behavior exhibited only minor changes when the small hole with a partially restrained edge was substituted for that with a totally free edge. This investigation, therefore, concentrated on two artificial boundary conditions at a pole and on the continuous pole. The artificial pole conditions used and their associated mathematical expressions are:

1. The totally free hole:

$$N_s = 0 ; N_{s\theta} = 0 ; Q_s = 0 ; M_s = 0 \quad (\text{AD-9})$$

2. The rigid plug:

$$U = 0 ; V = 0 ; Q_s = 0 ; \phi_s = 0 \quad (\text{AD-10})$$





### C. TYPES OF ANALYSIS

Three types of buckling analyses were conducted on the cap under each of the three pole conditions and these were:

1. The nonlinear axisymmetric analysis of the symmetrically loaded clamped spherical cap.
2. The bifurcation buckling analysis of the symmetrically loaded clamped spherical cap with nonlinear prebuckling axisymmetric displacements.
3. The nonlinear collapse analysis of the asymmetrically loaded clamped spherical cap.

In the artificial pole cases, hole and plug radii were taken as 0.17%, 1.70% and 3.30% of the shell meridian. The SATANS analyses used a 100 station meridian for the axisymmetric cases, a 66 station meridian with three harmonics for the bifurcation buckling cases and a 40 station meridian with five harmonics for the nonsymmetric collapse cases.



### III. DISCUSSION

The results of the SATANS analyses are presented in Table XI for all cases. Also presented are the normal deflections of a point located at 47.5% of the meridian which is near the maximum displacement for each case.

#### A. THE $\lambda = 6$ SHALLOW CAP

##### 1. The Axisymmetric Analysis

In Table XI, the buckling load is seen to be basically unaffected by the altered pole conditions. The normal displacement, however, is seen to show a marked sensitivity to the pole conditions. Figure 21 shows this sensitivity. In the figure, the upper curve is the deflection shape of the cap at incipient buckling with a continuous pole, and the lower curves represent the percent error induced in the normal displacement at incipient buckling by the introduction of artificial poles. The 0.17% plug and the 0.17% hole behaved identically. Holes, in general, produced an average 20% error in the normal displacement and this error existed over the entire shell. The plugs, preserving the continuity of the structure, produced an average 10% error, but again, this error extended over the entire shell. Figure 22 shows the behavior of the meridional force  $N_s$  for the continuous pole case, and the  $N_s$  error due to the artificial pole conditions, also at incipient buckling. Large errors existed in all cases over the first third of



TABLE XI

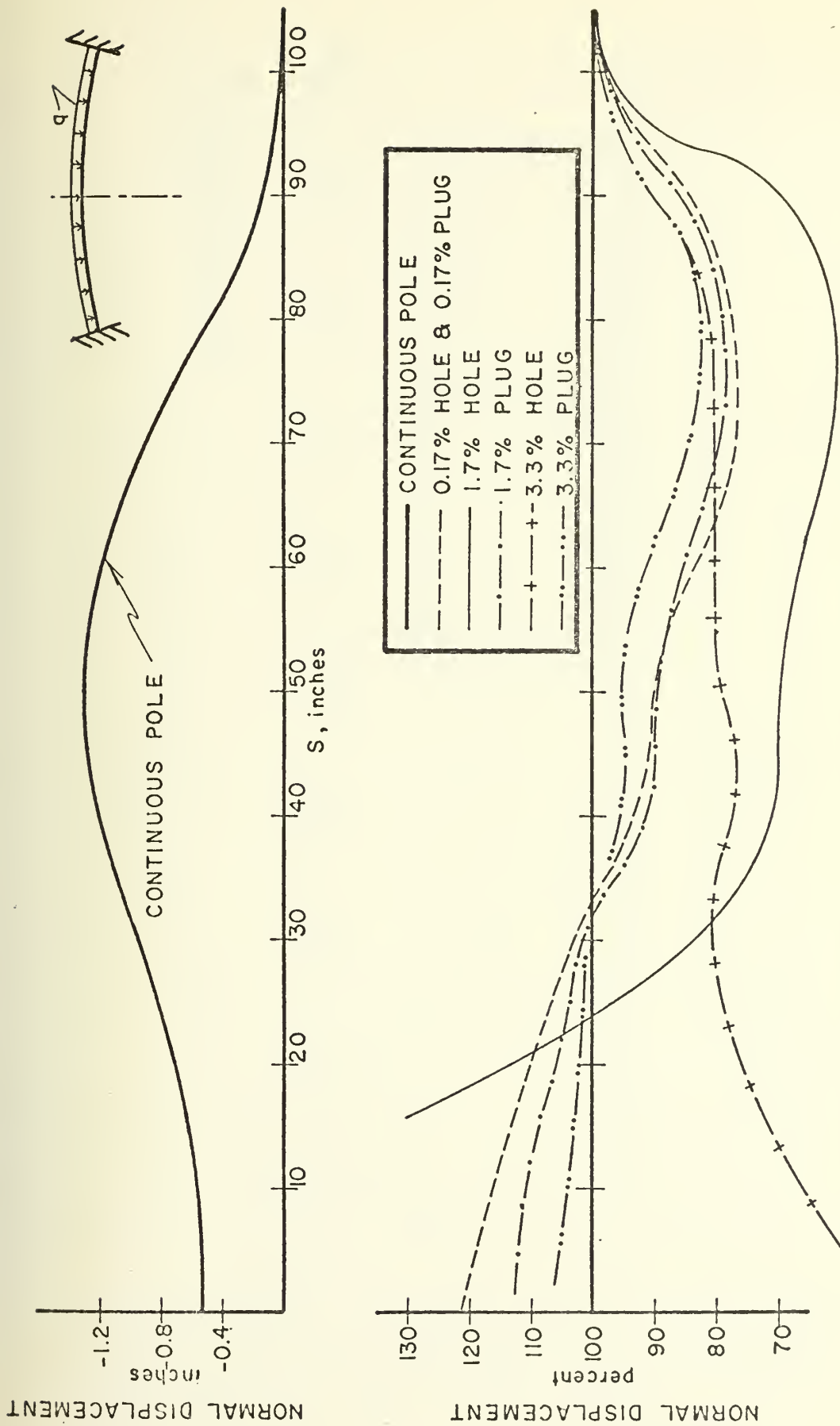
SHALLOW CAP ( $\lambda=6$ ) BUCKLING LOADS AND DISPLACEMENTS AT A POINT

ANALYSIS TYPE	POLE CONDITION	MERIDIONAL STATIONS/ HARMONICS	q/q <sub>o</sub>	NORMAL DEFLECTION AT 47.5% MERIDIAN (inches)	
Axisymmetric Buckling - Symmetric Load	Pole	-	0.9950*	-	
		30/1	1.0610	1.3720	
		100/1	1.0200	1.3200	
	Hole	-0.17%	100/1	0.9720	1.1600
		-1.70%	100/1	0.9690	1.0560
		-3.30%	100/1	0.9620	1.0290
	Plug	-0.17%	100/1	0.9720	1.2570
		-1.70%	100/1	0.9770	1.1630
		-3.30%	100/1	0.9900	1.2290
	Bifurcation Buckling - Symmetric Load	Pole	-	0.7750*	-
30/3			0.7851	0.6386	
66/3			0.7752	0.6188	
Hole		-0.17%	66/3	0.7719	0.6356
		-1.70%	66/3	0.7835	0.6562
		-3.30%	66/3	0.7392	0.6264
Plug		-0.17%	66/3	0.7719	0.6356
		-1.70%	66/3	0.7726	0.6438
		-3.30%	66/3	0.7713	0.6513
Collapse Analysis - Asymmetric Load		Pole	-	0.7100†	-
	40/5		0.5391	0.9830	
	Hole	-0.17%	40/5	0.5363	1.0780
		-1.70%	40/5	0.5389	1.0060
		-3.30%	40/5	0.5962	1.4110
	Plug	-0.17%	40/5	0.5978	0.9478
		-1.70%	40/5	0.6290	0.8100
		-3.30%	40/5	0.7576	0.7248

\* Huang [Ref. 16]

† Famili and Archer [Ref. 17]



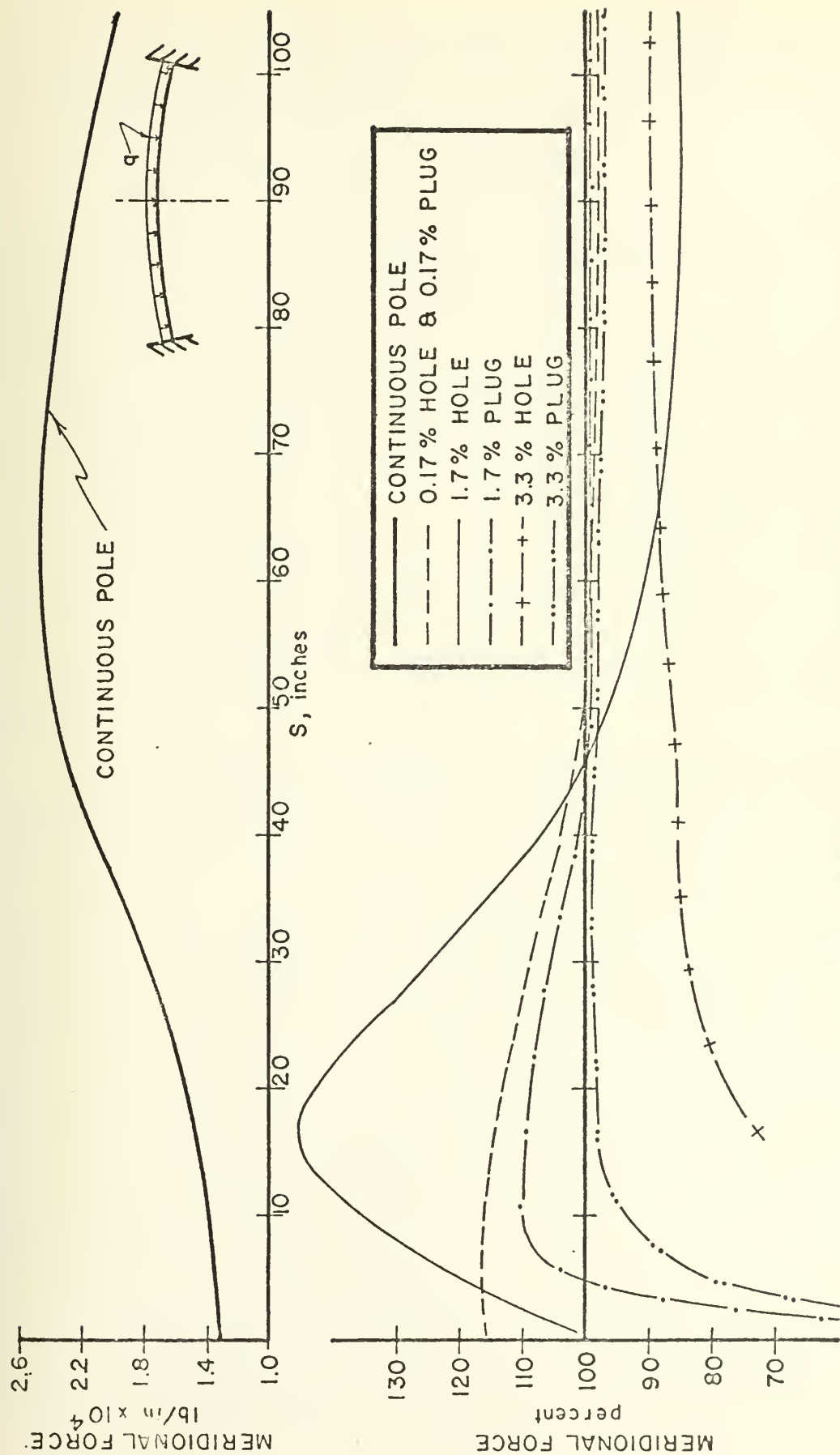


NORMAL DISPLACEMENT ERROR, AXISYMMETRIC ANALYSIS,  $\lambda=6$  CAP

FIGURE 21







MERIDIONAL FORCE ERROR, AXISYMMETRIC ANALYSIS,  $\lambda=6$  CAP

FIGURE 22



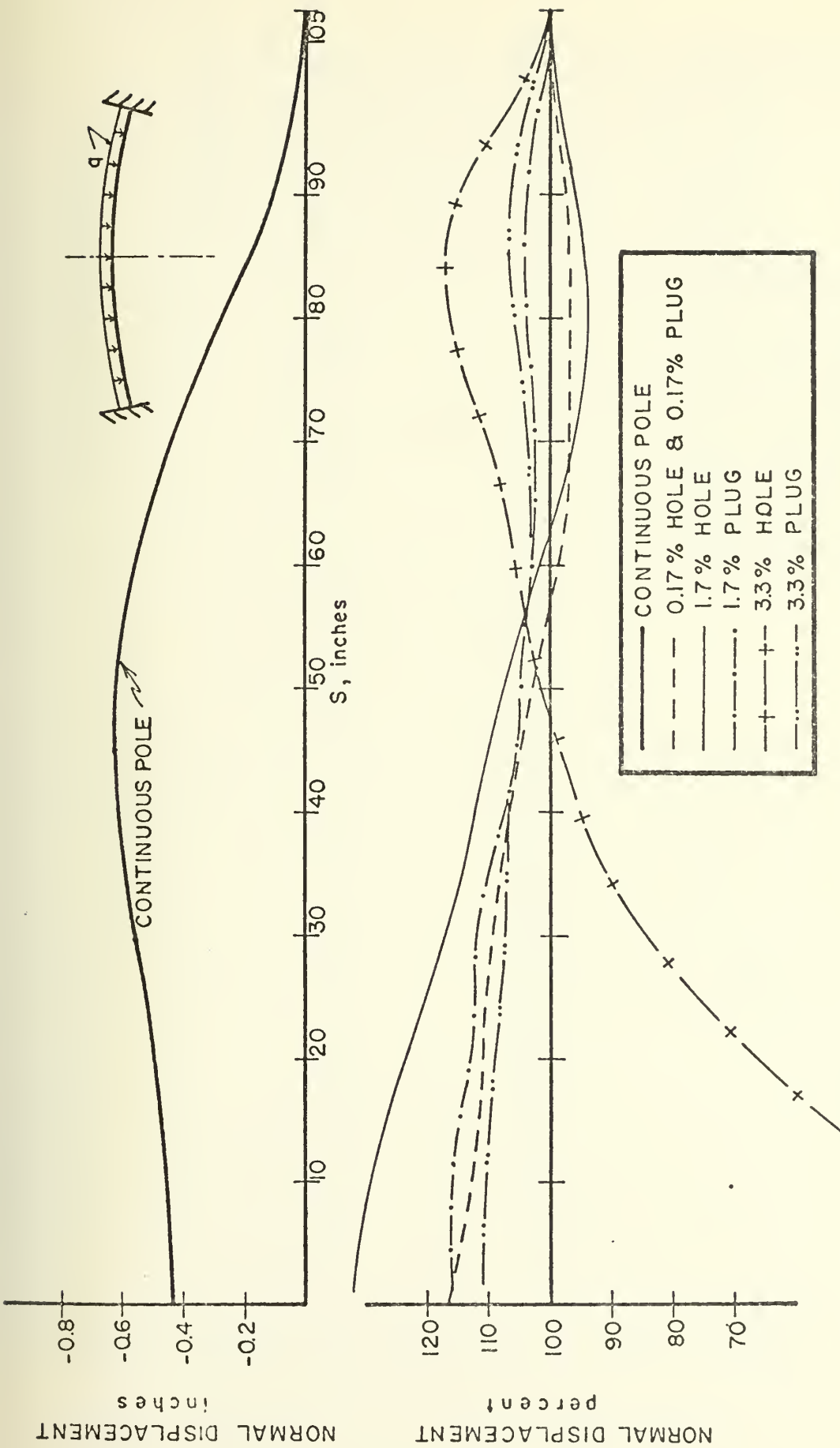
the meridian and were an average of 10% or less for the remainder of the meridian.

## 2. Bifurcation Buckling Analysis

In this analysis, the shell buckling load appears to be insensitive to artificial pole conditions for the case of the plugs, and shows some sensitivity in the case of the holes. This is surprising since bifurcation buckling of the  $\lambda = 6$  cap occurs in the  $\text{Cos}(2\theta)$  mode. While equations (AD-8) show that no rotations exist at the pole in this mode, rotations certainly do exist at 1.7% and 3.3% meridian due to the buckling mode. The equations for the rigid plug's boundary conditions (equations (AD-10) ) specifically prevent this rotation, while those for the hole (equations (AD-9) ) do not.

Examination of Figures 23 and 24 show that the displacement and force distributions of the plugs at incipient buckling to be less erroneous, again, than the poles. In Figure 23, an average 10% displacement error occurs over the entire shell for the plugs, while holes of 1.7% and 3.3% meridian cause large errors over much of the shell. This trend is repeated in Figure 24, although the errors are not as large. From this analysis, the indications are that the 1.7% hole is a poor artificial pole and a 3.3% hole is unacceptable as it causes a 4.6% error in buckling load and over 40% error in some regions in both normal displacement and meridional force distributions. Larger hole sizes would apparently increase these errors.

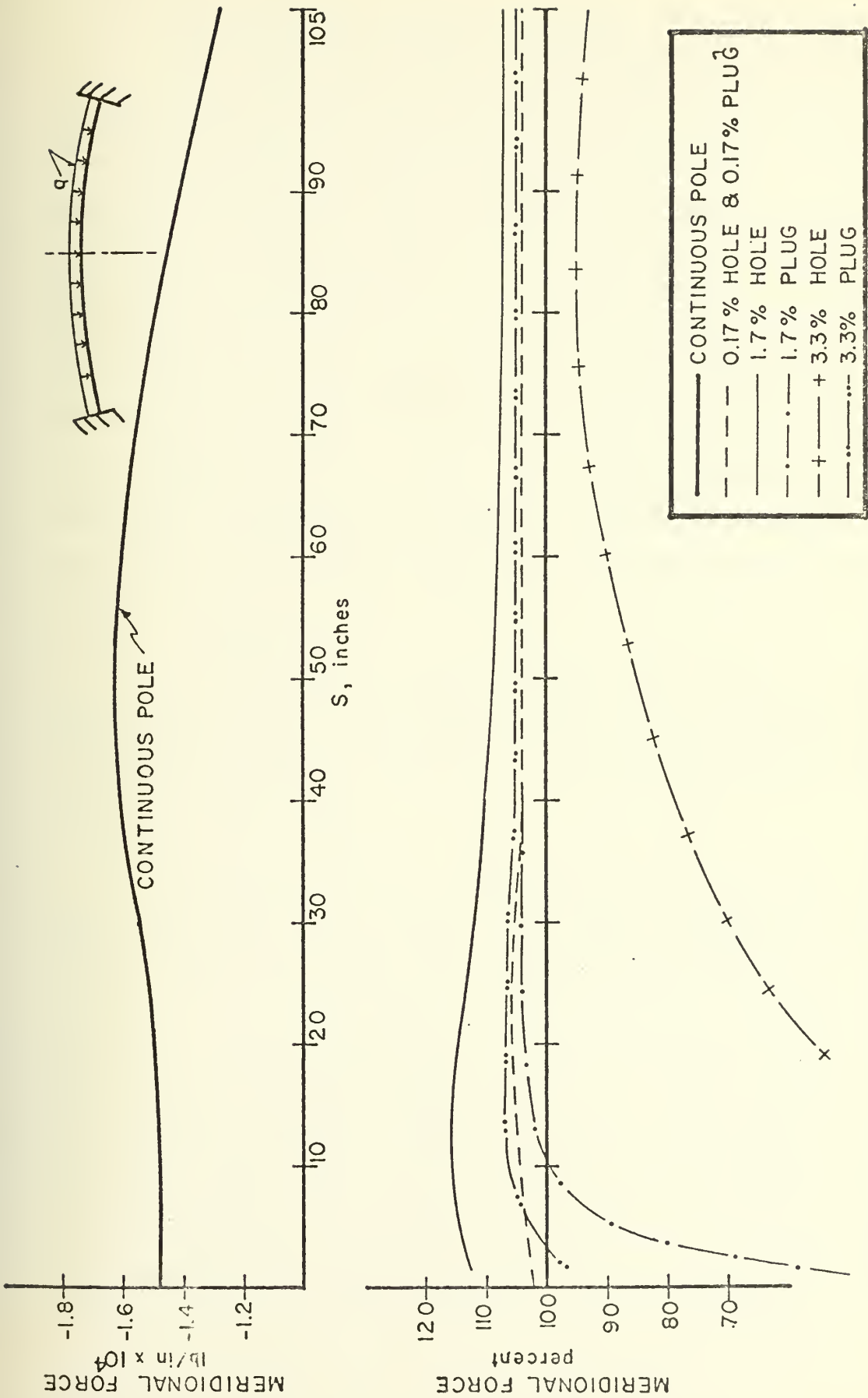




NORMAL DISPLACEMENT ERROR, BIFURCATION BUCKLING ANALYSIS,  $\lambda = 6$  CAP

FIGURE 23





MERIDIONAL FORCE ERROR, BIFURCATION BUCKLING ANALYSIS,  $\lambda = 6$  CAP

FIGURE 24





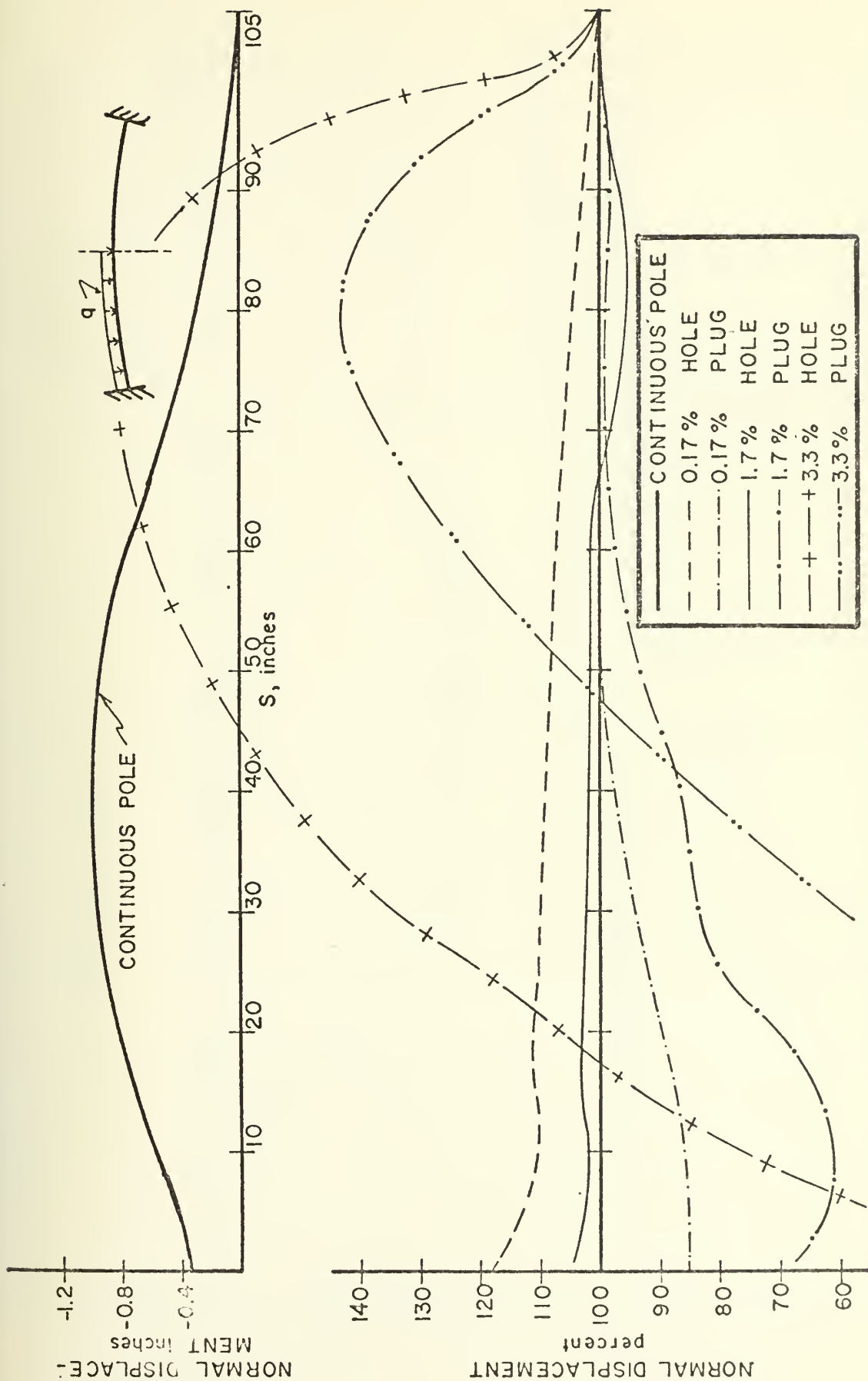
### 3. Nonsymmetric Collapse Analysis

The results for the collapse analysis are also presented in Table XI, and in Figures 25 and 26 for the  $\theta = 0^\circ$  meridian, which is symmetrically located under the loaded region. In Table XI, it is shown that the buckling loads of the cap with rigid plugs are quite erroneous (10.8%, 16.6% and 41.4% for the 0.17%, 1.7% and 3.3% plugs, respectively) while those for the small holes are quite reasonable. In Figures 25 and 26, it is seen that the small holes cause an average error of 10% in both the normal displacement and meridional force distributions at incipient buckling over the entire shell, while the errors caused by the rigid plugs is large.

In an asymmetrically loaded shell, large rotations will exist at the pole and the restrictions imposed by the rigid plug appear to make it an unacceptable artificial pole for use in this case.

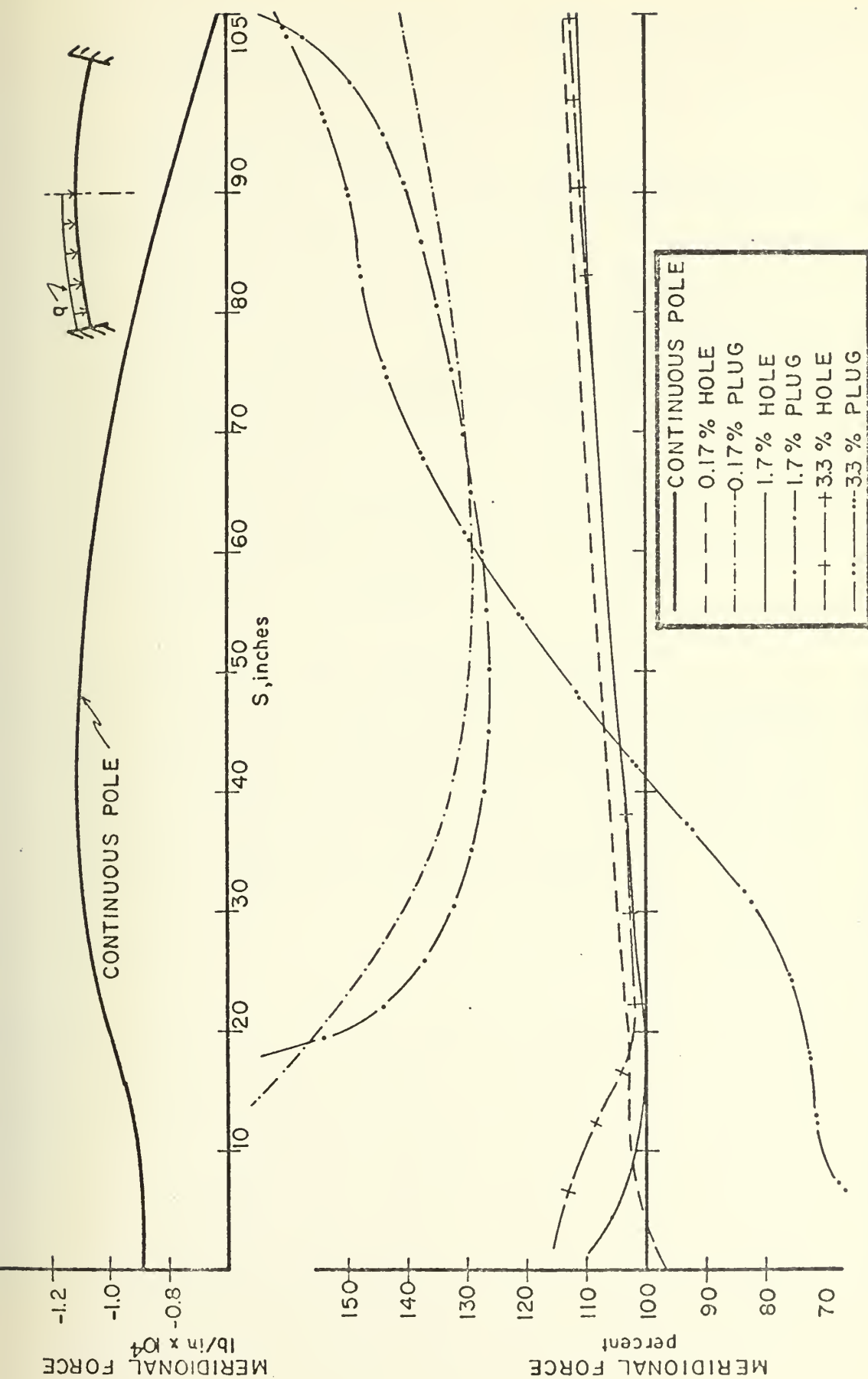
Figures 25 and 26 also indicate that a 1.7% hole is the best artificial pole for this case. Assuming such a 'best' hole size exists for another given shell or loading condition, an investigation similar to that presented here would have to be performed to find it. This is an inherently expensive and time consuming process and there is no guarantee that there is a 'best' hole size without its radius becoming so small that mathematical difficulties arise during the solution process. Consequently, the use of





NORMAL DISPLACEMENT ERROR, NONSYMMETRIC COLLAPSE ANALYSIS,  $\lambda=6$  CAP  
FIGURE 25





MERIDIONAL FORCE ERROR, NONSYMMETRIC COLLAPSE ANALYSIS,  $\lambda=6$  CAP

FIGURE 26



artificial pole conditions in nonsymmetric problems must be approached with caution.

#### B. THE $\lambda = 18$ SHALLOW CAP

A deeper shell with  $\lambda = 18$  was investigated in a similar fashion and produced similar results. The shell buckling load was negligibly affected (except in those cases already mentioned for the  $\lambda = 6$  shell) but displacement errors of up to 30% and meridional membrane force errors of an average 10-15% were noted. In general, the  $\lambda = 18$  shell appeared less sensitive to the type of artificial pole (except in the asymmetric case), but as sensitive to any artificial pole as the shallower  $\lambda = 6$  shell.

#### C. COMPARISONS WITH OTHER RESEARCHERS

As indicated in the introduction, various SATANS results were checked for validity with BOSOR and STAGS. These comparisons are presented with others in Table XII and very favorable agreement is seen to exist.





TABLE XII

SHALLOW CAP ( $\lambda=6$ ) BUCKLING LOADS COMPARISON

ANALYSIS TYPE	POLE CONDITION	SOURCE	$q/q_0$	REMARKS
Axisymmetric Buckling	Pole	Huang SATANS	0.9950	Classical /Ref. 167
			1.0200	100 Stations
Bifurcation Buckling	Pole	Huang BOSOR SATANS	0.7750	50 Stations /Ref. 167
			0.7756	40 Stations /Ref. 157
			0.7752	66 Stations, 3 harmonics
			0.7689	30x36 variably spaced grid /Ref. 157
	0.17% Hole	STAGS BOSOR SATANS	0.7736	40 Stations
			0.7719	66 Stations, 3 harmonics
			0.7711	30x36 variable spaced grid
			0.7747	40 Stations
	1.70% Plug	STAGS BOSOR SATANS	0.7716	66 Stations, 3 harmonics
			0.7100	7 Stations /Ref. 177
			0.6730	7 Stations, 4 harmonics /Ref. 187*
			0.6560	7 Stations, 10 harmonics *
Nonsymmetric Collapse	Pole	Famili & Archer SATANS	0.5380	20 Stations, 4 harmonics *
			0.5380	20 Stations, 10 harmonics *
			0.5391	40 Stations, 5 harmonics
			0.5233	22x92 variable spaced grid
	1.70% Hole	STAGS SATANS	0.5389	40 Stations, 5 harmonics

\* This result and the following three were taken from a discussion of the effects of the number of stations and harmonics on the buckling loads of the clamped spherical cap, contained in Ref. 18.



#### IV. CONCLUSIONS

The stability of the symmetrically loaded clamped shallow spherical shell appears to be fairly insensitive to artificial pole conditions in the axisymmetric and bifurcation buckling cases if the radius of the artificiality is kept at or below 3% of the meridian. In the case of the asymmetrically loaded shell, this insensitivity only applies when small holes are substituted for the pole. In general, the following additional conclusions can be drawn.

1. Sizable errors are introduced into the normal displacement and meridional membrane force distributions by the introduction of an artificial pole.
2. The displacement and force error distributions are sensitive to the size and type of artificial pole and are usually greater than 10% with some cases of over 30%, and they exist over the entire shell meridian.
3. Small rigid plugs appear to be the best polar models for symmetrically loaded shells. Apparently their continuity-preserving characteristics greatly outweigh their rotational-restricting characteristics.
4. Small holes appear to be the best polar models for asymmetrically loaded shells. Here, the rotational restrictions of the rigid plug make its use unacceptable. For this type of loading, an investigation will be required to determine the optimum hole size.



5. In general, the greater the displacement, or the higher the membrane force that would exist at a pole, the greater the error introduced by the use of an artificial pole.



APPENDIX A  
NONLINEAR TERMS

The nonlinear terms of equations (15) are given below.  
Terms involving the initial imperfection rotation terms  
along have been omitted as they cause no straining.

$$\begin{aligned}
 \phi_S^2 &= (\sigma_0/E_0)^2 \left\{ \left( \sum_0^\infty \phi_S^1(n) \cos n\theta \right)^2 + \left( \sum_1^\infty \phi_S^2(n) \sin n\theta \right)^2 \right. \\
 &\quad + 2 \left( \sum_0^\infty \phi_S^1(n) \cos n\theta \right) \left( \sum_1^\infty \phi_S^2(n) \sin n\theta \right) \\
 &\quad + 2 \left( \sum_0^\infty \phi_S^1(n) \cos n\theta \right) \left( \sum_0^\infty \bar{\phi}_S^1(n) \cos n\theta \right) \\
 &\quad + 2 \left( \sum_0^\infty \phi_S^1(n) \cos n\theta \right) \left( \sum_1^\infty \bar{\phi}_S^2(n) \sin n\theta \right) \\
 &\quad + 2 \left( \sum_1^\infty \phi_S^2(n) \sin n\theta \right) \left( \sum_0^\infty \bar{\phi}_S^1(n) \cos n\theta \right) \\
 &\quad \left. + 2 \left( \sum_1^\infty \phi_S^2(n) \sin n\theta \right) \left( \sum_1^\infty \bar{\phi}_S^2(n) \sin n\theta \right) \right\} \\
 &\equiv \sigma_0/E_0 \left( \sum_0^\infty \beta_S^1(n) \cos n\theta + \sum_1^\infty \beta_S^2(n) \sin n\theta \right)
 \end{aligned} \tag{A-1}$$





$$\begin{aligned}
\phi_{\theta}^2 &= (\sigma_0/E_0)^2 \left\{ \left( \sum_1^{\infty} \phi_{\theta}^1(n) \sin n\theta \right)^2 + \left( \sum_0^{\infty} \phi_{\theta}^2(n) \cos n\theta \right)^2 \right. \\
&\quad + 2 \left( \sum_1^{\infty} \phi_{\theta}^1(n) \sin n\theta \right) \left( \sum_0^{\infty} \phi_{\theta}^2(n) \cos n\theta \right) \\
&\quad + 2 \left( \sum_1^{\infty} \phi_{\theta}^1(n) \sin n\theta \right) \left( \sum_1^{\infty} \bar{\phi}_{\theta}^1(n) \sin n\theta \right) \\
&\quad + 2 \left( \sum_1^{\infty} \phi_{\theta}^1(n) \sin n\theta \right) \left( \sum_0^{\infty} \bar{\phi}_{\theta}^2(n) \cos n\theta \right) \\
&\quad + 2 \left( \sum_0^{\infty} \phi_{\theta}^2(n) \cos n\theta \right) \left( \sum_1^{\infty} \bar{\phi}_{\theta}^1(n) \sin n\theta \right) \\
&\quad \left. + 2 \left( \sum_0^{\infty} \phi_{\theta}^2(n) \cos n\theta \right) \left( \sum_0^{\infty} \bar{\phi}_{\theta}^2(n) \cos n\theta \right) \right\} \\
&\equiv \sigma_0/E_0 \left( \sum_0^{\infty} \beta_{\theta}^1(n) \cos n\theta + \sum_1^{\infty} \beta_{\theta}^2(n) \sin n\theta \right)
\end{aligned} \tag{A-2}$$

$$\begin{aligned}
\phi^2 &= (\sigma_0/E_0)^2 \left\{ \left( \sum_1^{\infty} \phi^1(n) \sin n\theta \right)^2 + \left( \sum_0^{\infty} \phi^2(n) \cos n\theta \right)^2 \right. \\
&\quad \left. + 2 \left( \sum_1^{\infty} \phi^1(n) \sin n\theta \right) \left( \sum_0^{\infty} \phi^2(n) \cos n\theta \right) \right\} \\
&\equiv \sigma_0/E_0 \left( \sum_1^{\infty} \beta^1(n) \sin n\theta + \sum_0^{\infty} \beta^2(n) \cos n\theta \right)
\end{aligned} \tag{A-3}$$



$$\begin{aligned}
\Phi_S \Phi_\theta &= (\sigma_0/E_0)^2 \left\{ \left( \sum_0^\infty \phi_S^1(n) \cos n\theta \right) \left( \sum_1^\infty \phi_\theta^1(n) \sin n\theta \right) \right. \\
&+ \left( \sum_0^\infty \phi_S^1(n) \cos n\theta \right) \left( \sum_0^\infty \phi_\theta^2(n) \cos n\theta \right) \\
&+ \left( \sum_1^\infty \phi_S^2(n) \sin n\theta \right) \left( \sum_1^\infty \phi_\theta^1(n) \sin n\theta \right) \\
&+ \left( \sum_1^\infty \phi_S^2(n) \sin n\theta \right) \left( \sum_0^\infty \phi_\theta^2(n) \cos n\theta \right) \\
&+ \left( \sum_0^\infty \phi_S^1(n) \cos n\theta \right) \left( \sum_1^\infty \bar{\phi}_\theta^1(n) \sin n\theta \right) \\
&+ \left( \sum_0^\infty \phi_S^1(n) \cos n\theta \right) \left( \sum_0^\infty \bar{\phi}_\theta^2(n) \cos n\theta \right) \\
&+ \left( \sum_1^\infty \phi_S^2(n) \sin n\theta \right) \left( \sum_1^\infty \bar{\phi}_\theta^1(n) \sin n\theta \right) \\
&+ \left( \sum_1^\infty \phi_S^2(n) \sin n\theta \right) \left( \sum_0^\infty \bar{\phi}_\theta^2(n) \cos n\theta \right) \\
&+ \left( \sum_0^\infty \bar{\phi}_S^1(n) \cos n\theta \right) \left( \sum_1^\infty \phi_\theta^1(n) \sin n\theta \right) \\
&+ \left( \sum_0^\infty \bar{\phi}_S^1(n) \cos n\theta \right) \left( \sum_0^\infty \phi_\theta^2(n) \cos n\theta \right) \\
&+ \left( \sum_1^\infty \bar{\phi}_S^2(n) \sin n\theta \right) \left( \sum_1^\infty \phi_\theta^1(n) \sin n\theta \right) \\
&+ \left. \left( \sum_1^\infty \bar{\phi}_S^2(n) \sin n\theta \right) \left( \sum_0^\infty \phi_\theta^2(n) \cos n\theta \right) \right\} \\
&\equiv \sigma_0/E_0 \left( \sum_0^\infty \beta_{S\theta}^1(n) \cos n\theta + \sum_1^\infty \beta_{S\theta}^2(n) \sin n\theta \right)
\end{aligned} \tag{A-4}$$



## APPENDIX B

### EIGENVALUE PROBLEM MATRIX ELEMENT DEFINITIONS

The elements of the  $\langle \bar{A} \rangle$  and  $\langle \bar{B} \rangle$  matrices used in the eigenvalue solution are defined below.

$$\begin{aligned}
 A_{11} &= G_{11} - E_{11}Q^2 \\
 A_{12} &= F_{12}Q \\
 A_{13} &= F_{13}Q \\
 A_{21} &= -F_{21}Q \\
 A_{22} &= -E_{22}Q^2 + G_{22} - G_{24}G_{42}/G_{44} \\
 A_{23} &= G_{23} + E_{23}Q^2 - G_{24}(G_{43} - E_{43}Q^2)/G_{44} \\
 A_{31} &= -F_{31}Q \\
 A_{32} &= G_{32} - E_{32}Q^2 - G_{42}(G_{34} - E_{34}Q^2)/G_{44} \\
 A_{33} &= G_{33} - E_{33}Q^2 - (G_{34} - E_{34}Q^2)(G_{43} - E_{43}Q^2)/G_{44}
 \end{aligned} \tag{B-1}$$

where

$$Q = m\pi/L$$

and where

$$\begin{aligned}
 B_{11} &= n^2/4 \\
 B_{12} &= nQ/4 \\
 B_{13} &= 0 \\
 B_{21} &= n^2/4 \\
 B_{22} &= Q^2/4 \\
 B_{23} &= 0 \\
 B_{31} &= 0 \\
 B_{32} &= 0 \\
 B_{33} &= Q^2
 \end{aligned} \tag{B-2}$$



and where all elements of the 4 x 4 matrices  $\underline{E}$ ,  $\underline{F}$  and  $\underline{G}$  are zero except for the following, defined as

$$\begin{aligned}
 E_{11} &= b \\
 E_{22} &= \frac{1}{2}(1-\nu)b + 9(1-\nu)d/(8R_0^2) \\
 E_{23} &= 3(1-\nu)dn/(2R_0^2) \\
 E_{32} &= E_{23} \\
 E_{33} &= 2(1-\nu)dn^2/R_0^2 \\
 E_{34} &= 1 \\
 E_{43} &= -d
 \end{aligned}
 \tag{B-3}$$

$$\begin{aligned}
 F_{12} &= \frac{1}{2}(1-\nu)bn/R_0 - 3(1-\nu)dn/(8R_0^3) \\
 F_{13} &= bv/R_0 - \frac{1}{2}(1-\nu)n^2/R_0^3 \\
 F_{21} &= -F_{12} \\
 F_{31} &= -F_{13}
 \end{aligned}
 \tag{B-4}$$

$$\begin{aligned}
 G_{11} &= -\frac{1}{2}(1-\nu)bn^2/R_0^2 - (1-\nu)dn^2/(8R_0^4) \\
 G_{22} &= -bn^2/R_0^2 - (1-\nu)(1+\nu)dn^2/R_0^4 \\
 G_{23} &= -bn/R_0^2 - (1-\nu)(1+\nu)dn^3/R_0^4 \\
 G_{24} &= -vn/R_0^2 \\
 G_{32} &= G_{23} \\
 G_{33} &= -vn^2/R_0^2 \\
 G_{42} &= vdn/R_0^2 \\
 G_{43} &= vdn^2/R_0^2 \\
 G_{44} &= -1
 \end{aligned}
 \tag{B-5}$$

and where

$$\begin{aligned}
 b &= \{(1-\nu)(1+\nu)\}^{-1} \\
 d &= (b/12)(h/r)^2
 \end{aligned}
 \tag{B-6}$$





# APPENDIX C

## INPUT DATA GUIDE FOR SATANS-I AND SATANS-II

<u>Card</u>	<u>Columns</u>	<u>Format</u>	<u>Item</u>	<u>Example</u>	<u>Meaning</u>
1	1-72	18A4	TITLE	-	Enter any 72 characters
-----					
2	1- 5	I5	NO	1	The problem number, 0<NO<10000.
2	6-10	L5	\$DYNAMC	F T	For a static analysis, set \$DYNAMC = F. For a dynamic analysis, set \$DYNAMC = T.
2	11-15	I5	IMODE	0 1	For no modal output data. For modal output data.
2	16-20	I5	NDIMEN	0 1	Dimensional output data. Nondimensional output.
2	21-25	I5	NTHMAX	8	Summed solution will be printed at NTHMAX merid- ians, 0<=NTHMAX<=36.
2	26-30	I5	IFREQ	3	Solution will be printed at the first station, every subsequent IFREQ station and the last sta- tion, 0<IFREQ<=KMAX.
2	31-35	I5	IPRINT	2	Every IPRINT converged solution will be print- ed.
2	36-40	I5	IBCINL	-1 0	If the shell has a pole at the first station. If the shell has no pole at the first station.
2	41-45	I5	IBCFNL	-1 0	If the shell has a pole at the last station. If the shell has no pole at the last station.



<u>Card</u>	<u>Columns</u>	<u>Format</u>	<u>Item</u>	<u>Example</u>	<u>Meaning</u>
2	46-50	I5	KMAX	35	Number of meridional stations. Note: KMAX<201 for SATANS-I without plots and KMAX<101 for SATANS-I with plots or for SATANS-II.
2	51-55	I5	MNMAX	7	Number of series coefficients used to describe the initial conditions, pressure and thermal loads (and initial imperfections if using SATANS-II). Note: For SATANS-I: 0<MAXM<11 and KMAX*MAXM<201. For SATANS-II: 0<MAXM<26 and KMAX*MAXM<951.
2	61-65	I5	LSMAX	1 99 750	For a linear analysis. Use many load steps for a nonlinear static analysis. For a dynamic analysis, LSMAX is the number of time increments, where $LSMAX = T_{max} / \Delta T$ .
2	66-70	I5	LCHMAX	3 0	The number of load step size reductions in a static analysis, recommended range = 2-4. For a dynamic analysis.
2	71-75	I5	ITRMAX	1 30	For a linear analysis. The number of iterations at a load or time step. For a nonlinear analysis, suggested range = 10-30, up to 50 for special cases.
2	76-80	I5	IC	0 1	Initial conditions. Set to 0 for a static analysis, or for a dynamic analysis where the shell is at rest at T=0. For a dynamic analysis with initial conditions.



<u>Card</u>	<u>Columns</u>	<u>Format</u>	<u>Item</u>	<u>Example</u>	<u>Meaning</u>
3	1-12	E12.3	NU	0.3	Poisson's ratio, $\nu$ .
3	12-24	E12.3	SIGO	1000.0 1.0	Reference stress level, $\sigma_0$ . If the input data is dimensional.
3	24-36	E12.3	ELAST	.3E8 1.0	Reference modulus of elasticity, $E_0$ . If the input data is dimensional.
3	37-48	E12.3	TKN	.4E-2 1.0	Reference thickness, $h_0$ . If the input data is dimensional.
3	49-60	E12.3	CHAR	8.16 1.0	Characteristic shell dimension, $a$ . If the input data is dimensional.
3	61-72	E12.3	TEEO	0.0 .996E-5	If a static analysis. Reference time, $T_0$ .
-----					
4	1-12	E12.3	DELOAD	0.2       .1823E-6	For a static analysis, DELOAD is the load increment. It remains unchanged until the solution fails to converge in ITRMAX iterations, when it is reduced by a factor of five. A maximum of LCHMAX such reductions will occur. For a dynamic analysis, DELOAD is the nondimensional time increment.
4	13-24	E12.3	EPS	0.01	The convergence criterion recommended range of $0.01 < EPS < 0.001$ .
-----					

Card 4A is only included for a SATANS-II analysis.

4A	1- 5	I5	JUMP	1	For an analysis using single series expansions.
				2	For an analysis using double series expansions.



<u>Card</u>	<u>Column</u>	<u>Format</u>	<u>Item</u>	<u>Example</u>	<u>Meaning</u>
4A	5-10	I5	MPERFS	0	An analysis without im- perfections.
				1	An analysis with imperfec- tions. Note: if JUMP=2, MPERFS may be 0 or 1. if JUMP=1, MPERFS must be 0 if MPERFS=1, JUMP must be 2.

-----

Include as many cards 5 as necessary to specify NTHMAX  
meridians. If NTHMAX equals 0, omit card 5.

5	1-72	6E12.3	10.0	A list of circumferential coordinates $\theta$ , in degrees and tenths, where the solution printout is de- sired. The list must have NTHMAX entries.
---	------	--------	------	---

-----

If IBCINL=-1, omit cards 6 through 14. If IBCFNL=-1, omit  
cards 15 through 23. Cards 6 through 23 describe the  
boundary conditions at the first, and then at the last sta-  
tion. The boundary conditions exist on the total variables,  
not on the individual harmonics. Loadings applied through  
specification of boundary conditions are taken in the zeroeth  
harmonic ( $n=0$ ) only, as the column matrix  $\{\ell\}$  is set to zero  
for harmonics greater than zero. The boundary conditions are  
dimensional. The format of cards 6 through 23 is 4E16.8.

<u>Card 6,15</u>	<u>Card 7,16</u>	<u>Card 8,17</u>	<u>Card 9, 18</u>	
$\Omega(1,1)$	$\Omega(1,2)$	$\Omega(1,3)$	$\Omega(1,4)$	$N_S$
$\Omega(2,1)$	$\Omega(2,2)$	$\Omega(2,3)$	$\Omega(2,4)$	$N_{S\theta}$
$\Omega(3,1)$	$\Omega(3,2)$	$\Omega(3,3)$	$\Omega(3,4)$	$Q_S$
$\Omega(4,1)$	$\Omega(4,2)$	$\Omega(4,3)$	$\Omega(4,4)$	$\Phi_S$

+





Card 10,19	Card 11,20	Card 12,21	Card 13,22		Card 14,23
$\Lambda(1,1)$	$\Lambda(1,2)$	$\Lambda(1,3)$	$\Lambda(1,4)$	$\left[ \begin{array}{c} U \\ V \\ W \\ M_s \end{array} \right]$	$= \left[ \begin{array}{c} \ell(1) \\ \ell(2) \\ \ell(3) \\ \ell(4) \end{array} \right]$
$\Lambda(2,1)$	$\Lambda(2,2)$	$\Lambda(2,3)$	$\Lambda(2,4)$		
$\Lambda(3,1)$	$\Lambda(3,2)$	$\Lambda(3,3)$	$\Lambda(3,4)$		
$\Lambda(4,1)$	$\Lambda(4,2)$	$\Lambda(4,3)$	$\Lambda(4,4)$		

---

Card 24 is:

1. Included for a SATANS-I static analysis.
2. Included but blank for a SATANS-I dynamic analysis.
3. Omitted for a SATANS-II analysis.

Card	Column	Format	Item	Example	Meaning
24	1- 2	L2	\$PLOTS	F	Indicates plots are NOT desired.
				T	Indicates plots are desired.
24	3- 4	L2	\$MODAL	F	Indicates plots are for summed solutions only
				T	Indicates plots are for modal solutions only.

For the remainder of card 24 entries, 0 indicates that no plots are desired for the particular item, and 1 indicates that they are desired. All graphs are plotted as the indicated item versus the station number. If a complete plot is desired, insure IFREQ=1.

24	5- 6	I2	IRADII	1	Plot the radii as computed by subroutine GEOM.
24	7- 8	I2	IGAMMA	1	Plot $\rho'/\rho$ as computed by subroutine GEOM.
24	9-10	I2	IOMEGS	1	Plot $\omega_s$ as computed by subroutine GEOM.
24	11-12	I2	IOMEGT	1	Plot $\omega_\theta$ as computed by subroutine GEOM.
24	13-14	I2	IDEOMS	1	Plot $\omega'_s$ as computed by subroutine GEOM.
24	15-16	I2	IBSTIF	1	Plot the stiffness d as computed by subroutine BDB.



<u>Card</u>	<u>Column</u>	<u>Format</u>	<u>Item</u>	<u>Example</u>	<u>Meaning</u>
24	17-18	I2	IDSTIF	1	Plot the stiffness $d$ as computed by the subroutine BDB.
24	19-20	I2	IBBSTF	1	Plot the stiffness $db/d\zeta$ as computed by subroutine BDB.
24	21-22	I2	IDDSTF	1	Plot the stiffness $dd/d\zeta$ as computed by subroutine BDB.
24	23-24	I2	IPR	1	Plot the normal component of the pressure load.
24	25-26	I2	IPS	1	Plot the meridional component of the pressure load.
24	27-28	I2	IPT	1	Plot the circumferential component of the pressure load.
24	29-30	I2	ITT	1	Plot the thermal load.
24	31-32	I2	IMT	1	Plot the thermal moment.
24	33-34	I2	IDTT	1	Plot $d/d\zeta$ of the thermal load.
24	35-36	I2	IDMT	1	Plot $d/d\zeta$ of the thermal moment.
24	37-38	I2	INS	1	Plot the meridional membrane force distribution.
24	39-40	I2	INTH	1	Plot the circumferential membrane force distribution
24	41-42	I2	INSTH	1	Plot the meridio-circumferential membrane force distribution.
24	43-44	I2	IQS	1	Plot the transverse force distribution.
24	45-46	I2	IMS	1	Plot the meridional moment distribution.
24	47-48	I2	IMTH	1	Plot the circumferential moment distribution.



<u>Card</u>	<u>Column</u>	<u>Format</u>	<u>Item</u>	<u>Example</u>	<u>Meaning</u>
24	49-50	I2	IMSTH	1	Plot the meridio-circumferential moment distribution.
24	51-52	I2	IU	1	Plot the meridional displacement distribution.
24	53-54	I2	IV	1	Plot the circumferential displacement distribution.
24	55-56	I2	IW	1	Plot the normal displacement distribution.
24	57-58	I2	IPHIS	1	Plot the meridional rotation distribution.
24	59-60	I2	IPHIT	1	Plot the circumferential rotation distribution.
24	61-62	I2	IPHI	1	Plot the meridio-circumferential rotation distribution.

-----

Insert imperfection data here for a SATANS-II analysis with imperfections. Insure format of the imperfection data is compatible with that specified in the user-written subroutine IMPERF.

-----

25	1- 2	I2	IRNAGN	0	Indicates this is the only run.
				1	Indicates another run is to be made. Add another complete set of data cards after this card is IRNAGN=1.



# APPENDIX D

## LISTING OF SATANS-I USER PREPARED SUBROUTINES

```

C*****
C    THIS PROGRAM SERVES AS THE 'MAIN' PROGRAM, AND CALLS SUBROUTINE
C    'SATANS' AT THE END OF A RUN, IT CHECKS 'IRNAGN' TO SEE IF
C    THERE IS ANOTHER RUN.
C*****
C    COMMON /BLRUN/ IRNAGN
C    1 CALL SATANS
C    CALL FLYNVY
C    IF (IRNAGN.EQ.1) GO TO 1
C    STOP
C    END

```

```

SUBROUTINE GEOM
C*****
C    THIS SUBROUTINE COMPUTES THE NONDIMENSIONAL GEOMETRY FUNCTIONS
C    OF THE SHELL.
C*****
C    REAL NU, LAM, LAM2, JAY, MT, LSD18, LSDIN, MASS
C    COMMON /IBL4/ KMAX, KL
C    COMMON /BL8/ R(200), GAM(200), OMT(200)
C    COMMON /BL11/ OMXI(200), PHEE, TO, T2
C    COMMON /BL17/ DEL
C    COMMON /BL20/ DEOMX(200)
C    COMMON /BL32/ TKN, ELAST, CHAR, SIGO
C    COMMON /BL102/ DELOAD
C    COMMON /BL103/ MASS(200)
C*****
C    GEOMETRY FOR CYLINDER A-14
C    R(S) = INFINITY
C    R(TH) = 4.0 INCHES
C    S = 8.16 INCHES
C    KMAX = 35 STATIONS
C    A = 8.16 INCHES (CHARACTERISTIC SHELL DIMENSION)
C*****

```





```

DEL=8.16/(8.16*34.0)
RO=4.0/8.16
RORCP=1.0/RO
DO 1 K=1,KMAX
  R(K)=RO
  GAM(K)=0.0
  OMT(K)=RORCP
  OMXI(K)=0.0
  DEOMX(K)=0.0
1 RETURN
END

```

```

SUBROUTINE BD3(K,B,DB,D,DD)
C*****
C THIS SUBROUTINE COMPUTES THE NONDIMENSIONAL INPLANE AND BENDING
C STIFFNESSES OF THE SHELL.
C*****
REAL NU,LAM,LAM2,JAY,MT,LSD18,LSDIN,MASS
COMMON /BL15/ NU,U1(10),V1(10),W1(10),V2(10),W2(10),U3(10),
1 V3(10),W3(10)
COMMON /BL17/ DEL
COMMON /BL32/ TKN,ELAST,CHAR,SIG/
C*****
C NONDIMENSIONAL STIFFNESS QUANTITIES FOR CYLINDER A-14
C WHERE:
C E(0)=15,800,000 PSI
C H(0)=0.00437 INCHES
C A=8.16 INCHES
C*****
B=1./12.
D=B/12.
DB=0.
DD=0.
RETURN
END

```



```

C** SUBROUTINE PLOAD(K)
C** THIS SUBROUTINE ESTABLISHES THE NONDIMENSIONAL FOURIER
C** COEFFICIENTS OF THE LOADS APPLIED TO THE SHELL, AND ALSO
C** ESTABLISHES THE MODES TO BE CONSIDERED IN THE ANALYSIS.
C** ESTABLISHMENT OF MODES CAN ALSO BE ACCOMPLISHED IN SUBROUTINE
C** TLOAD.
C**
COMMON /IBL1/ MNMAX
COMMON /IBL2/ NN(10), MNINIT
COMMON /IBL4/ KMAX, KL
COMMON /INL8/ LSTEP, ITR
COMMON /BL3/ PR(10), PX(10), PT(10)
COMMON /BL6/ Z(4,220), SOE, OSE, ALOAD
COMMON /BL8/ R(200), GAM(200), OMT(200)
COMMON /BL32/ TKN, ELAST, CHAR, SIGO
COMMON /BL102/ DELOAD
COMMON /BL103/ MASS(200)
C** THIS LOADING IS FOR ESTABLISHMENT OF THE CYLINDER A-14 BIFURCA-
C** TION BUCKLING LOADING IN THE 21ST HARMONIC. AS MODAL TRIGGERS, AS THE
C** THE PRESSURE LOADING DEFINED HERE ACTS AS MODAL TRIGGERS, AS THE
C** AXIAL LOAD IS INTRODUCED THROUGH THE BOUNDARY CONDITIONS.
C** A=CHAR/(SIGO*TKN)
NN(1)=0
NN(2)=21
PR(1)=0.0000001*A
PR(2)=0.0000001*A
RETURN
END

```



```

C*****
C SUBROUTINE TLOAD(K)
C THIS SUBROUTINE DESCRIBES THE THERMAL LOADING ON THE SHELL.
C*****
REAL NU
COMMON /IBL1/ MNMAX
COMMON /IBL2/ NN(10), MNINIT
COMMON /IBL8/ LSTEP, ITR
COMMON /BL5/ TT(10), EMT(10), DT(10), DMT(10)
COMMON /BL6/ Z(4,220), SOE, OSE, ALOAD
COMMON /BL15/ NU, UI(10), VI(10), W1(10), V2(10), U2(10), W2(10), U3(10),
1 V3(10), W3(10)
COMMON /BL32/ TKN, ELAST, CHAR, SIGO
C*****
C THERE IS NO THERMAL LOADING ON CYLINDER A-14.
C*****
RETURN
END

```

```

C*****
C SUBROUTINE INITL
C THIS SUBROUTINE DESCRIBES THE INITIAL CONDITIONS FOR DYNAMIC RUNS
C*****
IMPLICIT LOGICAL*1 ($)
COMMON /IBL1/ MNMAX
COMMON /IBL2/ NN(10), MNINIT
COMMON /IBL4/ KMAX, KL
COMMON /IBL9/ MAXM
COMMON /IBL12/ KMAX1, KMAX2, NCONV
COMMON /BL6/ Z(4,220), SOE, OSE, ALOAD
COMMON /BL32/ TKN, ELAST, CHAR, SIGO
COMMON /BL100/ TEO, $DYNAMC
COMMON /BL101/ ZO(4,220), Z2(4,220), Z3(4,220), DELSD
COMMON /BL104/ ZDOT(4,220)
C*****
C THERE ARE NO INITIAL CONDITIONS FOR A STATIC ANALYSIS.
C*****
RETURN
END

```



# APPENDIX E

## LISTING OF SATANS-I

THIS LISTING COMPRISES THE STORABLE PACKAGE OF SATANS-I AND CONTAINS THE FOLLOWING SUBROUTINES:

SATANS	STATIC	DYNAMC	OUTPUT
PLOT2	FLYNVY	FORCE	MATINV
ABC	PANDD	MODES	HJ
POLE	PLOTT	SCALIT	DRAWIT
ROUND	XANDZ	PLOTT	PMATRX
UPDATE	INLPOL	FNLPOL	PHIBET
EFG	TEAETA		

```

SUBROUTINE SATANS
C*****
C    THIS SUBROUTINE READS ALL DATA, PRINTS THE OUTPUT TITLE PAGE,
C    AND PASSES CONTROL TO ONE OF THE MAJOR CONTROLLING SUBROUTINES
C*****
C*****
C    IMPLICIT LOGICAL#1 ($)
REAL*4 NU,LAM,LAM2,JAY,MT, LSD18, LSDIN, MASS
COMMON /IBL1/ MNMAX
COMMON /IBL4/ KMAX,KL
COMMON /IBL5/ IBCINL, IBCFNL
COMMON /IBL9/ MAXM
COMMON /IBL10/ IFREQ, NTHMAX
COMMON /IBL13/ ITRMAX, LSMAX
COMMON /BL13/ OMEG1(4,4), CAPL1(4,4), CAPLL(4,4),
1 COMMON /BL15/ UJ,U1(10),V1(10),W1(10),V2(10),U2(10),W2(10),U3(10),
1 COMMON /BL16/ EPS
COMMON /BL18/ ELI(4),ELL(4)
COMMON /BL19/ TH(36)
COMMON /BL32/ TKN,ELAST,CHAR,SIGO
COMMON /BL100/ TEOO,$DYNMC
COMMON /BL102/ DELOAD
COMMON /BLPLOT/ ITRADI1, IGAMMA, IOMEGS, IOMEGT, IDEOMS, IBSTIF, IDSTIF,
1 IBBSTF, IDBSTF, IPR, IPS, IPT, ITT, IMT, IDTT, IDMT, INS,
2 INTN, INSTH, IQS, IMS, IMTH, IMSTH, IU, IV, IW, IPHIS,
3 IPHIT, IPHI, $PLOTS, $MODAL
C*****

```





```

COMMON /BLDATA/ TITLE,NO,IMODE,NDIMEN,IPRINT,LCHMAX,IC
COMMON /BLRUN/ IRNAGN
DIMENSION TITLE (18)
C*****
C READ IN DATA FOR THIS RUN
C*****
READ (5,100) TITLE
READ (5,101) NO,$DYNMC,IMODE,NDIMEN,NTHMAX,IFREQ,IPRINT,IBCINL,
1 IBCFNL,KMAX,MNMAX,MAXM,LSMAX,LCHMAX,ITRMAX,IC
READ (5,102) NU,SIGO,ELAST,TKN,CHAR,TEEO
READ (5,103) DELOAD,EPS
IF (NTHMAX.EQ.0) GO TO 1
READ (5,104) (TH(NTH),NTH=1,NTHMAX)
DO 2 NTH=1,NTHMAX
2 TH(NTH)=TH(NTH)*6.2831853/360.0
1 IF (IBCFNL.EQ.0) READ (5,105) OMEG1,CAPL1,ELL
IF (IBCFNL.EQ.0) READ (5,105) OMEG1,CAPL1,ELL
READ (5,106) $PLOTS,$MODAL,IRADII,IGAMMA,IOMEGS,IOMEGT,IDEOMS,
1 IBSTIF,IDSTIF,IBBSTIF,IBBSTIF,IPR,IPS,IPT,ITT,IMT,IDTT,
2 IDMT,INS,INTH,INSTH,IQS,IMS,IMTH,IMSTH,IU,IV,IW,
3 IPHIS,IPHIT,IPHI
READ (5,107) IRNAGN
C*****
C THIS CONCLUDES DATA READ-IN FOR THIS RUN.
C PRINT OUT PERTINENT DATA.
C*****
WRITE (6,200) NO
WRITE (6,201) TITLE
WRITE (6,202)
IF (IBCFNL.LT.0) WRITE (6,203)
IF (IBCFNL.LT.0) GO TO 3
WRITE (6,204)
WRITE (6,205) (OMEG1(1,J),J=1,4),(CAPL1(1,J),J=1,4),ELL(1)
WRITE (6,206) (OMEG1(2,J),J=1,4),(CAPL1(2,J),J=1,4),ELL(2)
WRITE (6,207) (OMEG1(3,J),J=1,4),(CAPL1(3,J),J=1,4),ELL(3)
WRITE (6,208) (OMEG1(4,J),J=1,4),(CAPL1(4,J),J=1,4),ELL(4)
3 IF (IBCFNL.LT.0) WRITE (6,209)
IF (IBCFNL.LT.0) GO TO 4
WRITE (6,210)
WRITE (6,205) (OMEG1(1,J),J=1,4),(CAPL1(1,J),J=1,4),ELL(1)
WRITE (6,206) (OMEG1(2,J),J=1,4),(CAPL1(2,J),J=1,4),ELL(2)
WRITE (6,207) (OMEG1(3,J),J=1,4),(CAPL1(3,J),J=1,4),ELL(3)
WRITE (6,208) (OMEG1(4,J),J=1,4),(CAPL1(4,J),J=1,4),ELL(4)
4 IF ($DYNMC) GO TO 5
WRITE (6,212) KMAX,MAXM,DELOAD,LSMAX,ITRMAX,LCHMAX,EPS
WRITE (6,213) CHAR,TKN,ELAST,SIGO,NU
IF (.NOT.$PLOTS) GO TO 6

```



```

1 ICHCK1=IABS(IRADII)+IABS(IGAMMA)+IABS(IOMEGS)+IABS(IQMEGT)
2 +IABS(IDEOMS)+IABS(IBSTIF)+IABS(IDSTIF)+IABS(IBBSTF)
3 +IABS(IDDSTF)+IABS(IPR)+IABS(IPS)+IABS(IPT)+IABS(ITT)
  (ICHCK1.GT.0) WRITE (6,214)
  IF (ICHCK1.EQ.0) GO TO 8
  IF (IRADII.NE.0) WRITE (6,215)
  IF (IGAMMA.NE.0) WRITE (6,216)
  IF (IOMEGS.NE.0) WRITE (6,217)
  IF (IOMEGT.NE.0) WRITE (6,218)
  IF (IDEOMS.NE.0) WRITE (6,219)
  IF (IBSTIF.NE.0) WRITE (6,220)
  IF (IDSTIF.NE.0) WRITE (6,221)
  IF (IBBSTF.NE.0) WRITE (6,222)
  IF (IPR.NE.0) WRITE (6,223)
  IF (IPS.NE.0) WRITE (6,224)
  IF (IPT.NE.0) WRITE (6,225)
  IF (ITT.NE.0) WRITE (6,226)
  IF (IMT.NE.0) WRITE (6,227)
  IF (IDTT.NE.0) WRITE (6,228)
  IF (IDMT.NE.0) WRITE (6,229)
  IF (IDMT.NE.0) WRITE (6,230)
8 ICHCK1=IABS(INS)+IABS(INTH)+IABS(INSTH)+IABS(IQS)+IABS(IMS)
1 +IABS(IMTH)+IABS(IMSTH)+IABS(IU)+IABS(IV)+IABS(IW)
2 +IABS(IPHIS)+IABS(IPHIT)+IABS(IPHI)
  IF ((ICHCK1.GT.0).AND.$MODAL) WRITE (6,231)
  IF ((ICHCK1.GT.0).AND..NOT.$MODAL) WRITE (6,232)
  IF (ICHCK1.EQ.0) GO TO 9
  IF (INS.NE.0) WRITE (6,233)
  IF (INTH.NE.0) WRITE (6,234)
  IF (INSTH.NE.0) WRITE (6,235)
  IF (IQS.NE.0) WRITE (6,236)
  IF (IMS.NE.0) WRITE (6,237)
  IF (IMTH.NE.0) WRITE (6,238)
  IF (IMSTH.NE.0) WRITE (6,239)
  IF (IU.NE.0) WRITE (6,240)
  IF (IV.NE.0) WRITE (6,241)
  IF (IW.NE.0) WRITE (6,242)
  IF (IPHIS.NE.0) WRITE (6,243)
  IF (IPHIT.NE.0) WRITE (6,244)
  IF (IPHI.NE.0) WRITE (6,245)
9 GO TO 6
5 WRITE (6,246) KMAX,MAXM,DELOAD,LSMAX,ITRMAX,EPS
  WRITE (6,247) CHAR,TKN,ELAST,SIGO,TEEO,NU
6 IF (INTHMAX.EQ.0) GO TO 7
  WRITE (6,248)
  WRITE (6,249) (TH(NTH),NTH=1,NTHMAX)
7 IF (NDIMEN.EQ.1) WRITE (6,250)

```









```

1, 'REFERENCE THICKNESS-----, E12.4/5X, 'REFERENCE EL00001720
2ASTICITY-----, E12.4/5X, 'REFERENCE STRESS-----00001730
3-----, E12.4/5X, 'POISSONS RATIO-----00001740
4, E12.4/5X, 'PLOTS HAVE BEEN REQUESTED FOR THE BELOW LISTED GE00001750
214 FORMAT (, T10, 'STIFFNESS OR LOADING QUANTITIES: ', 000001760
1OMETRY, 'RADIUS', 00001770
215 FORMAT (, T70, 'GAMMA', 00001780
216 FORMAT (, T70, 'OMEGA-S', 00001790
217 FORMAT (, T70, 'OMEGA-THETA', 00001800
218 FORMAT (, T70, 'DEOMEGA-S', 00001810
219 FORMAT (, T70, 'DEOMEGA-S', 00001820
220 FORMAT (, T70, 'B-STIFFNESS', 00001830
221 FORMAT (, T70, 'D-STIFFNESS', 00001840
222 FORMAT (, T70, 'B-PRIME', 00001850
223 FORMAT (, T70, 'D-PRIME', 00001860
224 FORMAT (, T70, 'PRESSURE LOADING - NORMAL', 00001870
225 FORMAT (, T70, 'PRESSURE LOADING - MERIDIONAL', 00001880
226 FORMAT (, T70, 'PRESSURE LOADING - CIRCUMFERENTIAL', 00001890
227 FORMAT (, T70, 'THERMAL LOADING', 00001900
228 FORMAT (, T70, 'THERMAL MOMENT', 00001910
229 FORMAT (, T70, 'D-THERMAL LOADING', 00001920
230 FORMAT (, T70, 'D-THERMAL MOMENT', 00001930
231 FORMAT (, T20, 'PLOTS HAVE BEEN REQUESTED FOR THE BELOW LISTED MO000001940
1DAL QUANTITIES: ', 000001950
232 FORMAT (, T20, 'PLOTS HAVE BEEN REQUESTED FOR THE BELOW LISTED SU000001960
1MMED QUANTITIES: ', 000001970
233 FORMAT (, T70, 'N-S', 00001980
234 FORMAT (, T70, 'N-THETA', 00001990
235 FORMAT (, T70, 'N-S-THETA', 00002000
236 FORMAT (, T70, 'Q-S', 00002010
237 FORMAT (, T70, 'M-S', 00002020
238 FORMAT (, T70, 'M-THETA', 00002030
239 FORMAT (, T70, 'M-S-THETA', 00002040
240 FORMAT (, T70, 'U', 00002050
242 FORMAT (, T70, 'W', 00002060
241 FORMAT (, T70, 'V', 00002070
243 FORMAT (, T70, 'PHI-S', 00002080
244 FORMAT (, T70, 'PHI-THETA', 00002090
245 FORMAT (, T70, 'PHI', 00002100
246 FORMAT (, T4X, 'NUMBER OF STATIONS-----, I3/5X, 'N00002110
1UMBER OF MODES-----, I3/5X, 'INCREMENTAL TIME-----00002120
2-----, E9.4/5X, 'MAXIMUM NUMBER OF TIME STEPS-----00002130
3-----, I5/5X, 'MAXIMUM NUMBER OF ITERATIONS-----, I3/5X, 'C00002140
4ONVERGENCE CRITERION-----, F6.4/5X, 'E12.4/5X, 'N00002150
247 FORMAT (, T4X, 'CHARACTERISTIC SHELL DIMENSION-----, E12.4/5X, '000002160
1, 'REFERENCE THICKNESS-----, E12.4/5X, 'REFERENCE EL000002170
2ASTICITY-----, E12.4/5X, 'REFERENCE STRESS-----000002180
3-----, E12.4/5X, 'REFERENCE TIME-----000002190

```





```

4,E12.4/5X,POISSONS RATIO-----,E12.4//)
248 FORMAT (,T20,CIRCUMFERENTIAL COORDINATES FOR THE PRINT RECORD,
1 IN RADIAN MEASURE,ARE:)//)
249 FORMAT (,T10,6F16.10)
250 FORMAT (///,T20,THE DATA PRINTED IS NON-DIMENSIONAL.)
251 FORMAT (///,T20,THE DATA PRINTED IS DIMENSIONAL.)
RETURN
END
00002200
00002210
00002220
00002230
00002240
00002250
00002260
00002270

```

```

SUBROUTINE STATIC
*****
THIS SUBROUTINE IS THE MAJOR CONTROLLING ROUTINE FOR ALL STATIC
ANALYSIS PROBLEMS. IT CONDUCTS INITIALIZATION, PREPARES INPUT
MATERIALS FOR PLOTTING IF REQ'D, DETERMINES SHELL GEOMETRY, STIFF-
NESSES,LOADING (PHYSICAL AND/OR THERMAL), AND INITIAL CONDITIONS.
IT CONTROLS PROBLEM SOLUTION PROCEDURE.
*****
IMPLICIT LOGICAL*1 ($)
REAL*4 NU,LAM,LAM2,JAY,MT,LSD18,LSD1N,MASS
COMMON /IBL1/ MNMAX
COMMON /IBL2/ N(10),MNINIT
COMMON /IBL3/ MO,M1,M2,M3
COMMON /IBL4/ KMAX,KL
COMMON /IBL5/ IBCINL,IBCFNL
COMMON /IBL6/ KLL
COMMON /IBL7/ MNMAXC,MAXD(10),MAXS(10),MAXSY(10),IS(10,10),
1 JS(10,10),ID(10,10),JD(10,10),IJS(10)
COMMON /IBL8/ LSTEP,ITR
COMMON /IBL9/ MAXM
COMMON /IBL10/ IFREQ,NTHMAX
COMMON /IBL11/ ICORFL,IPASS
COMMON /IBL12/ KMAX1,KMAX2,NCONV
COMMON /IBL13/ ITRMAX,LSMAX
COMMON /BL1/ A(4,4),BEE(4,4),C(4,4)
COMMON /BL3/ PR(10),PX(10),PT(10)
COMMON /BL4/ P(4,4,200),X(4,200),ZF1M(4,4,10),ZF2M(4,4,10),
00000010
00000020
00000030
00000040
00000050
00000060
00000070
00000080
00000090
00000100
00000110
00000120
00000130
00000140
00000150
00000160
00000170
00000180
00000190
00000200
00000210
00000220
00000230
00000240
00000250
00000260
00000270
00000280

```







```

4      YNSTH(100),YQS(100),YMS(100),YMT(100),YMSTH(100),00000770
5      YU(100),YV(100),YW(100),YPHIS(100),YPHIT(100),00000780
6      YPHI(100),XSTATN(100)00000790
COMMON /BLDATA/ TITLE,NO,IMODE,NDIMEN,IPRINT,LCHMAX,IC00000800
DIMENSION SIGT(2),SIGC(2),TITLE(18)00000810
C*****00000820
WRITE (6,8888)00000830
DELSD=DELOAD*DELOAD00000840
KL=KMAX-100000850
KLL=KMAX-200000860
KMAX1=KMAX+100000870
KMAX2=KMAX+200000880
AK=KL00000890
SIGT(1)=SIGO*TKN00000900
SIGT(2)=SIGO/ELAST00000910
SIGC(1)=SIGO*CHAR/ELAST00000920
SIGC(2)=SIGO*TKN**3/CHAR00000930
IF (IBCINL.LT.0) GO TO 1400000940
DO 98 I=1,400000950
DO 98 J=1,400000960
KKLM=J/4+100000970
OMEG1(I,J)=OMEG1(I,J)*SIGT(KKLM)00000980
CAPL1(I,J)=CAPL1(I,J)*SIGC(KKLM)00000990
IF (IBCFNL.LT.0) GO TO 170001000
DO 99 I=1,40001010
DO 99 J=1,40001020
KKLM=J/4+10001030
OMEG1(I,J)=OMEG1(I,J)*SIGT(KKLM)0001040
CAPL1(I,J)=CAPL1(I,J)*SIGC(KKLM)0001050
LAM=TKN/CHAR0001060
SOE=SIGO/ELAST0001070
OSE=.5*SOE0001080
SI=1.0-NU0001090
SI=1.0+NU0001100
LAM2=LAM**20001110
IF (NDIMEN.LT.1) GO TO 2280001120
SIGO=1.00001130
ELAST=1.00001140
TKN=1.00001150
CHAR=1.00001160
DO 230 M=1,MAXM0001170
N(M)=0.00001180
PX(M)=0.00001190
PT(M)=0.00001200
PR(M)=0.00001210
TT(M)=0.00001220
MT(M)=0.00001230
DT(M)=0.00001240

```



```

DMT(M)=0.0
MAXD(M)=0
MAXS(M)=3
MAXSY(M)=0
CALL GEOM
1 ICHCK1=IABS(IGAMMA)+IABS(IOMEGS)+IABS(IOMEGT)+IABS(IDEOMS)
  ICHCK2=IABS(IRADII)+IABS(IBSTIF)+IABS(IDSTIF)+IABS(IBBSTF)+IABS(IDDSTF)
  IF (.NOT.$PLOTS) GO TO 1
  DO 2 K=1,KMAX
  XSTATN(K)=FLOAT(K)
2 IF (ICHCK1.EQ.0) GO TO 1
  DO 1 K=1,KMAX
  XRADII(K)=R(K)*CHAR
  YGAMMA(K)=GAM(K)/CHAR
  YOMEGS(K)=OMXI(K)/CHAR
  YOMEGT(K)=OMT(K)/CHAR
  YDEOMS(K)=DEOMX(K)/(CHAR*CHAR)
1 CONTINUE
DO 86 K=1,KMAX
86 MASS(K)=0.
  WRITE(6,802)
DO 978 K=1,KMAX
  RKK=R(K)*CHAR
  OMXIK=OMXI(K)/CHAR
  GAMK=GAM(K)/CHAR
  OMTK=OMT(K)/CHAR
  DEOMXK=DEOMX(K)/(CHAR*CHAR)
978 WRITE(6,803) K,RKK,GAMK,OMXIK,OMTK,DEOMXK
805 M0=0
  M1=0
  M2=0
  M3=0
  ABN=CHAR/SIGO/TKN
  ZN=SIGO*TKN
  WRITE(6,112)
DO 888 K=1,KMAX
  CALL BDB(K,B,DB,D,DD)
  BST=ELAST*TKN
  ZST=ELAST*TKN**3
  B=B*BST
  D=D*ZST
  DB=DB/CHAR*BST
  DD=DD/CHAR*ZST
  WRITE(6,71) K,B,D,DB,DD
  IF (.NOT.$PLOTS.OR.(ICHCK2.EQ.0)) GO TO 888
  YBSTIF(K)=B
  YDSTIF(K)=D

```





```

YBBSIF(K)=DB
YDDSTF(K)=DD
888 CONTINUE
CALL PLOAD(1)
CALL TLOAD(1)
DO 889 M=1,MNMAX
WRITE(6,113) N(M)
WRITE(6,114)
1 ICHCK3=IABS(IPR)+IABS(IPS)+IABS(IPT)+IABS(ITT)+IABS(IMT)
+IABS(IDTT)+IABS(IDMT)
DO 890 K=1,KMAX
CALL PLOAD(K)
CALL TLOAD(K)
PRM=PR(M)/ABN
PTM=PT(M)/ABN
PXM=PX(M)/ABN
TTM=TT(M)*ZN
EMTM=MT(M)/CHAR*ZN*TKN*TKN
DTM=DT(M)/CHAR*ZN
DMTM=DMT(M)*ZN*TKN*TKN/(CHAR*CHAR)
WRITE(6,115) K,PRM,PTM,TTM,EMTM,DTM,DMTM
IF (.NOT.$PLOTS.OR.(ICHCK3.EQ.0)) GO TO 890
YPR(K)=PRM
YPS(K)=PXM
YPT(K)=PTM
YTT(K)=TTM
YMT(K)=EMTM
YDT(K)=DTM
YDMT(K)=DMTM
890 CONTINUE
IF (M.EQ.1) ICHCK3=ICHCK1+ICHCK2+ICHCK3
IF ($PLOTS.AND.(ICHCK3.GT.0)) CALL PLOT1(M)
889 CONTINUE
DELSQ=DEL*2
TDL1=.5/DEL
TDEL=2.*DEL
MNINIT=1
MNMAXO=MNMAX
DO 23 I=1,4
DO 20 J=1,4
UNIT(I,J)=0.0
20 IF(I.EQ.J) UNIT(I,J)=1.0
NMAX=MAXM*KMAX2
DO 22 K=1,NMAX
DO 22 I=1,4
ZDOT(I,K)=0.0
ZO(I,K)=J.0
Z2(I,K)=0.0

```



```

22  Z3(I,K)=0.0
    Z(I,K)=0.0
    ALOAD=DELOAD
    CALL PMATRIX
    LSTEP=1
    LCHANG=0
    ITR=1
    ICORFL=0
    IF(MNMAX.EQ.MAXM) ICORFL=1
    IPASS=0
    CALL XANDZ
    IF(ITRMAX.EQ.1) GO TO 50
    MNMAXO=MNMAX
    IF(IPASS.LT.2) CALL MODES
    IF((NCONV.EQ.1).AND.(ITR.GT.1)) GO TO 50
    IF(ITR.LT.ITRMAX) GO TO 23
    IF(LCHANG.LT.LCHMAX) GO TO 30
    WRITE(6,220) NO
    GO TO 500
400 FL=LSTEP
    FI=IPRINT
    LI=LSTEP/IPRINT
    FLI=LI-FL/FI
    IF(FLI.EQ.0.) CALL OUTPUT(IMODE)
    IF(LSTEP.EQ.1) ITR=1
    IF(LSTEP.EQ.1) ITRPR=1
    IF(ITR.GT.ITRPR) ITRPR=ITR
    IF(LSTEP.GE.LSMAX) GO TO 360
60  DO 61 MN=1,MNMAXO
    DO 61 K=1,KMAX2
    IK=K+(MN-1)*KMAX2
    DO 61 I=1,4
    ZN=2.0*Z(I,IK)-ZO(I,IK)
    ZO(I,IK)=Z(I,IK)
    Z(I,IK)=ZN
    IF(LSTEP.GE.LSMAX) GO TO 360
62  ALOAD=ALOAD+DELOAD
    LSTEP=LSTEP+1
    ITR=1
    GO TO 400
360 WRITE(6,221) NO
    GO TO 500
23  ITR=ITR+1
    GO TO 400
30  IF(LSTEP-1) 310,310,320
310 WRITE(6,223)
    GO TO 500

```

```

00002210
00002220
00002230
00002240
00002250
00002260
00002270
00002280
00002290
00002300
00002310
00002320
00002330
00002340
00002350
00002360
00002370
00002380
00002390
00002400
00002410
00002420
00002430
00002440
00002450
00002460
00002470
00002480
00002490
00002500
00002510
00002520
00002530
00002540
00002550
00002560
00002570
00002580
00002590
00002600
00002610
00002620
00002630
00002640
00002650
00002660
00002670
00002680

```



```

320 WRITE(6,222)
    LCHANG=LCHANG+1
    LSTEP=LSTEP-1
    ALOAD=ALOAD-DELOAD
    DELOAD=DELOAD/5.0
    DO 32 MN=1,MNMAX0
    DO 32 K=1,KMAX2
    IK=K+(MN-1)*KMAX2
    DO 32 I=1,4
    32 Z(I,IK)=Z0(I,IK)
    GO TO 62
C*****
71 FORMAT(20X,I3,4X,4E20.6)
112 FORMAT(///17X,12H STATION 20H B STIFFNESS 20H D ST0002820
113 IF FNESS 20H 20H D PRIME //)
113 FORMAT(///25X,44HPRESSURE AND TEMPERATURE COEFFICIENTS FOR N=I3,8H00002830
114 FORMAT(5X,7HSTATION,3X,15H PR 15H MT 15H PX 15H DTT 100002870
15H PT 15H DMT //)
115 FORMAT(6X,I3,7X,7E15.4)
220 FORMAT(1H1,80H THE MAXIMUM NUMBER OF LOAD CHANGES HAVE BEEN0002880
1EN MADE. END PROBLEM NUMBERI4)
221 FORMAT(1H1,79H THE MAXIMUM NUMBER OF LOAD STEPS HAVE BEEN0002890
1 TAKEN. END PROBLEM NUMBERI4)
222 FORMAT(1H1,119H THE SOLUTION DID NOT CONVERGE WITHIN THE M0002910
1AXIMUM NUMBER OF ITERATIONS. THE LOAD FACTOR HAS BEEN DIVIDED BY 0002930
25.)
223 FORMAT(1H1,69H THE SOLUTION DID NOT CONVERGE FOR THE FIRS0002940
1T LOAD INCREMENT ./11X,71HLOOK FOR AN ERROR IN THE INPUT DATA, OR T0002950
2RY A SMALLER VALUE FOR DELOAD.)
802 FORMAT(1H1,17X,15H STATION 16H RADIUS 16H DEOMEGA S //)
16H OMEGA S 16H THETA16H GAMMA 0003000
803 FORMAT(20X,I3,9X,5E16.4)
8888 FORMAT ('0',T20,'EXECUTING IN SUBROUTINE "STATIC"',)
500 RETURN
END
0002690
0002700
0002710
0002720
0002730
0002740
0002750
0002760
0002770
0002780
0002790
0002800
0002810
0002820
0002830
0002840
0002850
0002860
0002870
0002880
0002890
0002900
0002910
0002920
0002930
0002940
0002950
0002960
0002970
0002980
0002990
0003000
0003010
0003020
0003030
0003040
0003050

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SUBROUTINE DYNAMC
C*****
C      THIS SUBROUTINE IS ONE OF THE MAJOR CONTROLLING SUBROUTINES FOR
C      ALL DYNAMIC ANALYSIS PROBLEMS.  IT OPERATES IN A FASHION SIMILAR
C      TO SUBROUTINE STATIC.
C*****
      IMPLICIT LOGICAL*1 ($)
      REAL*4 NU,LAM,LAM2,JAY,MT, LSD18,LSDIN,MASS
      COMMON /IBL1/ MNMAX
      COMMON /IBL2/ N(10), MNINIT
      COMMON /IBL3/ MO,M1,M2,M3
      COMMON /IBL4/ KMAX,KL
      COMMON /IBL5/ IBCINL,IBCFNL
      COMMON /IBL6/ KLL
      COMMON /IBL7/ MNMAXO,MAXD(10),MAXS(10),MAXSY(10),IS(10,10),
1      JS(10,10),ID(10,10),JD(10,10),IJS(10),
      LSTEP,ITR
      COMMON /IBL8/ MAXM
      COMMON /IBL9/ IFREQ,NTHMAX
      COMMON /IBL10/ ICORFL,IPASS
      COMMON /IBL11/ KMAX1,KMAX2,NCONV
      COMMON /IBL12/ ITRMAX,LSMAX
      COMMON /IBL13/ A(4,4),BEE(4,4),C(4,4)
      COMMON /BL1/ PR(10),PX(10),PT(10)
      COMMON /BL3/ P(4,4,200),X(4,200),ZF1M(4,4,10),
      ZF3M(4,4,10),ZF4M(4,4,10)
      COMMON /BL4/ TT(10),MT(10),DT(10),DMT(10)
1      MT: APPEARS AS 'EMT' IN SUBROUTINES INLPOL & FNLPOL
      Z(4,220),SOE,OSE,ALOAD
      COMMON /BL6/ D1,S1
      COMMON /BL7/ R(200),GAM(200),OMT(200)
      COMMON /BL8/ FFS(4,10),ELIS(4),GEES(4,10)
      COMMON /BL9/ PHIX(10),PHIT(10),PHI(10)
      COMMON /BL10/ OMXI(200),PHEE,T0,T2
      COMMON /BL11/ TDLI,TDEL
      COMMON /BL12/ OMEGI(4,4),CAPL1(4,4),OMEGL(4,4),CAPLL(4,4),
      UNIT(4,4)
1      LAM2,LSD18,LSDIN
      COMMON /BL14/ NU,U1(10),V1(10),W1(10),V2(10),U2(10),W2(10),U3(10),
      V3(10),W3(10)
1      EPS
      COMMON /BL16/ DEL
      COMMON /BL17/ ELL(4)
      COMMON /BL18/ TH(36)
      COMMON /BL19/ DEOMX(200)
      COMMON /BL20/ JAY(4,4),H(4,4)
      COMMON /BL23/ DL(4,4,10),DG(4,4,10),DF(4,4,10)
      COMMON /BL24/

```





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COMMON /BL25/ E(4,4),F(4,4),G(4,4)
COMMON /BL27/ BX3(10),BT3(10),BXT3(10),BE3(10)
COMMON /BL28/ EXX3(10),ETX3(10),ETX3(10),EX3(10),ET3(10)
COMMON /BL29/ BX1(10),BT1(10),BXT1(10),BE1(10),BX2(10),BT2(10),
1 BX2(10),BE2(10)
COMMON /BL30/ EXX1(10),ETX1(10),ETX1(10),EX1(10),ET1(10),EXX2(10),
1 ETX2(10),ETX2(10),EX2(10),ET2(10)
COMMON /BL31/ DELSQ,EXT1(10)
COMMON /BL32/ TKN,ELAST,CHAR,SIGO
COMMON /BL34/ DEE(4,4,200),DST(4,4,230)
COMMON /BL100/ TEED,$DYNMC
COMMON /BL101/ ZO(4,220),Z2(4,220),Z3(4,220),DELSO
COMMON /BL102/ DELOAD
COMMON /BL103/ MASS(200)
COMMON /BL104/ ZDOT(4,220)
COMMON /BL110/ TX(10),TTH(10),THT(10),MX(10),MTH(10),MXT(10),
1 QS(10)
COMMON /BL111/ ABZ,ABZO,ABZN,ABZ3,DD2
COMMON /BLPLOT/ IRADII,IGAMMA,IOMEGS,IOMEGT,IDEOMS,IBSTIF,IDSTIF,
1 IBBSTF,IDDSTF,IPR,IPS,IPT,ITT,IMT,IDTT,IDMT,INS,
2 INTH,INSTH,IQS,IMS,IMTH,IMSTH,IU,IV,IW,IPHIS,
3 IPHIT,IPHI,$PLOTS,$MODAL
COMMON /BLPLT1/ XRADII(100),YGAMMA(100),YOMEGS(100),YOMEGT(100),
1 YDEOMS(100),YBSTIF(100),YDSTIF(100),YBBSIF(100),
2 YDDSTF(100),YPR(100),YPS(100),YPT(100),YIT(100),
3 YMT(100),YDTT(100),YDMI(100),YNS(100),YNTH(100),
4 YNSTH(100),YQS(100),YMS(100),YMTTH(100),YMSTH(100),
5 YU(100),YV(100),YW(100),YPHIS(100),YPHIT(100),
6 YPHI(100),XSTATN(100)
COMMON /BLDATA/ TITLE,NO,IMODE,NDIMEN,IPRINT,LCHMAX,IC
DIMENSION SIGT(2),SIGC(2),TITLE(18)
DIMENSION VBAR(10),AVB(10)
C*****
WRITE (6,888)
DELSO=DELOAD*DELOAD
KL=KMAX-1
KLL=KMAX-2
KMAX1=KMAX+1
KMAX2=KMAX+2
AK=KL
SIGT(1)=SIGO*TKN
SIGC(2)=SIGO*ELAST
SIGC(1)=SIGO*CHAR/ELAST
SIGC(2)=SIGO*TKN**3/CHAR
IF (IBCNL.LT.0) GO TO 14
DO 98 I=1,4
DO 98 J=1,4
KKLM=J/4+1
00000490
00000500
00000510
00000520
00000530
00000540
00000550
00000560
00000570
00000580
00000590
00000600
00000610
00000620
00000630
00000640
00000650
00000660
00000670
00000680
00000690
00000700
00000710
00000720
00000730
00000740
00000750
00000760
00000770
00000780
00000790
00000800
00000810
00000820
00000830
00000840
00000850
00000860
00000870
00000880
00000890
00000900
00000910
00000920
00000930
00000940
00000950
00000960

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```

98 OMEGL(I,J)=OMEG1(I,J)*SIGT(KKLM)
14 CAPL1(I,J)=CAPL1(I,J)*SIGC(KKLM)
  IF(IBCFLN.LT.0) GO TO 17
  DO 99 I=1,4
  DO 99 J=1,4
  KKLM=J/4+1
  OMEGL(I,J)=OMEG1(I,J)*SIGT(KKLM)
99 CAPL1(I,J)=CAPL1(I,J)*SIGC(KKLM)
17 LAM=TKN/CHAR
  SOE=SIGO/ELAST
  SOE=.5*SOE
  DI=1.0-NU
  SI=1.0+NU
  LAM2=LAM**2
  IF(NDIMEN.LT.1) GO TO 228
  SIGO=1.0
  ELAST=1.0
  TKN=1.0
  CHAR=1.0
228 DO 230 M=1,MAXM
  N(M)=0.0
  PX(M)=0.0
  PT(M)=0.0
  PR(M)=0.0
  TT(M)=0.0
  MT(M)=0.0
  DT(M)=0.0
  MAXD(M)=0.0
  MAXS(M)=0.0
  MAXSY(M)=0.0
  CALL GEOM
  ICHK1=IABS(IGAMMA)+IABS(IOMEGS)+IABS(IOMEGT)+IABS(IDEOMS)
1  ICHK1+IABS(IRADII)
  ICHK2=IABS(IBSTIF)+IABS(IDSTIF)+IABS(IBBSTF)+IABS(IDDSTF)
  IF(.NOT.$PLOTS) GO TO 1
  DO 2 K=1,KMAX
2  XSTATN(K)=FLOAT(K)
  IF (ICCHK1.EQ.0) GO TO 1
  DO 1 K=1,KMAX
  XRADII(K)=R(K)*CHAR
  YGAMMA(K)=GAM(K)/CHAR
  YOMEGS(K)=OMXI(K)/CHAR
  YOMEGT(K)=OMT(K)/CHAR
  YDEOMS(K)=DEOMX(K)/(CHAR*CHAR)
1  CONTINUE
804 WRITE(6,810)
  TEED=TEEO

```

```

00000970
00000980
00000990
0001000
0001010
0001020
0001030
0001040
0001050
0001060
0001070
0001080
0001090
0001100
0001110
0001120
0001130
0001140
0001150
0001160
0001170
0001180
0001190
0001200
0001210
0001220
0001230
0001240
0001250
0001260
0001270
0001280
0001290
0001300
0001310
0001320
0001330
0001340
0001350
0001360
0001370
0001380
0001390
0001400
0001410
0001420
0001430
0001440

```



```

IF(NDIMEN.EQ.1) TEED=1.0
DO 979 K=1,KMAX
RKK=R(K)*CHAR
OMXIK=OMXI(K)/CHAR
GAMK=GAM(K)/CHAR
OMTK=OMT(K)/CHAR
DEOMXK=DEOMX(K)/(CHAR*CHAR)
AMSS=MASS(K)*TEED**2*ELAST*TKN/CHAR**2
979 WRITE(6,813) K,RKK,GAMK,OMXIK,OMTK,DEOMXK,AMSS
805 MO=0
M1=0
M2=0
M3=0
ABN=CHAR/SIGO/TKN
ZN=SIGC*TKN
WRITE(6,112)
DO 888 K=1,KMAX
CALL BDB(K,B,DB,D,DD)
BST=ELAST*TKN
ZST=ELAST*TKN**3
B=B*BST
D=D*ZST
DB=DB/CHAR*BST
DD=DD/CHAR*ZST
WRITE(6,71) K,B,D,DB,DD
IF (.NOT.$PLOTS.OR.(ICHECK2.EQ.0)) GO TO 888
YBSTIF(K)=B
YDSTIF(K)=D
YBBSTF(K)=DB
YDDSTF(K)=DD
888 CONTINUE
CALL PLOAD(1)
CALL TLOAD(1)
DELSQ=DEL**2
TDLI=.5/DEL
TDEL=2.0*DEL
MNINIT=J
MNAOXO=MNMAX
DO 20 I=1,4
DO 20 J=1,4
UNIT(I,J)=0.0
20 IF(I.EQ.J) UNIT(I,J)=1.0
NMFX=MAXM*KMAX2
DO 22 K=1,NMAX
DO 22 I=1,4
ZDOT(I,K)=0.0
Z0(I,K)=0.0
Z2(I,K)=0.0

```

```

00001450
00001460
00001470
00001480
00001490
00001500
00001510
00001520
00001530
00001540
00001550
00001560
00001570
00001580
00001590
00001600
00001610
00001620
00001630
00001640
00001650
00001660
00001670
00001680
00001690
00001700
00001710
00001720
00001730
00001740
00001750
00001760
00001770
00001780
00001790
00001800
00001810
00001820
00001830
00001840
00001850
00001860
00001870
00001880
00001890
00001900
00001910
00001920

```



```

22      Z3(I,K)=0.0
        Z(I,K)=0.0
        IF(IC.EQ.0) GO TO 834
        CALL INITL
        ACC=CHAR*SIGO/ELAST
        ACM=SIGO*TKN**3/CHAR
        DO 830 M=1,MNMAX
          MM=(M-1)*KMAX2
          WRITE(6,126) N(M)
          WRITE(6,127)
          DO 831 K=2,KMAX1
            MK=K+MM
            TU=ACC*ZO(1,MK)
            TV=ACC*ZO(2,MK)
            TW=ACC*ZO(3,MK)
            TM=ACM*ZO(4,MK)
            KK=K-1
            WRITE(6,71) KK,TU,TV,TW,TM
831      WRITE(6,129)
          DO 830 K=2,KMAX1
            ACC=CHAR*SIGO/(ELAST*TEEO)
            AMD=SIGO*TKN**3/(CHAR*TEEO)
            MK=K+MM
            TU=ACD*ZDOT(1,MK)
            TV=ACD*ZDOT(2,MK)
            TW=ACD*ZDOT(3,MK)
            TM=AMD*ZDOT(4,MK)
            KK=K-1
            WRITE(6,71) KK,TU,TV,TW,TM
          DO 830 I=1,4
            Z(I,MK)=ZO(I,MK)+ZDOT(I,MK)*DELOAD
            Z2(I,MK)=ZO(I,MK)-ZDOT(I,MK)*DELOAD
830      Z3(I,MK)=ZO(I,MK)-2.*ZDOT(I,MK)*DELOAD
834      CONTINUE
          ALOAD=1.0
          CALL PMATRX
          LSTEP=1
          LCHANG=0
          ITR=1
          ICORFL=0
          IF(MNMAX.EQ.MAXM) ICORFL=1
          IPASS=0
          CALL XANDZ
          IF(ITRMAX.EQ.1) GO TO 50
          MNMAXO=MNMAX
          IF(IPASS.LT.2) CALL MODES
          IF(NCONV.EQ.1) GO TO 50
          IF(ITR.LT.ITRMAX) GO TO 23

```





```

50      GO TO 365
      FL=LSTEP
      FI=IPRINT
      LI=LSTEP/IPRINT
      FLI=LI
      FT=FLI-FL/FI
      IF(FT.EQ.0.) CALL OUTPUT(IMODE)
      IF(LSTEP.EQ.1) ITR=1
      IF(LSTEP.EQ.1) ITRPR=1
      IF(ITR.GT.ITRPR) ITRPR=ITR
      IF(LSTEP.GE.LSMAX) GO TO 360
      DO 65 MN=1,MNMAXO
      DO 65 K=1,KMAX2
      IK=K+(MN-1)*KMAX2
      DO 65 I=1,4
      ZN=3.0*(Z(I,IK)-ZO(I,IK))+Z2(I,IK)
      Z3(I,IK)=Z2(I,IK)
      Z2(I,IK)=ZO(I,IK)
      ZO(I,IK)=Z(I,IK)
      Z(I,IK)=ZN
      ALOAD=1.0
      LSTEP=LSTEP+1
      ITR=1
      GO TO 430
23      ITR=ITR+1
      GO TO 400
360      WRITE(6,271)
      WRITE(6,188) (AVB(M),M=1,MAXM)
      WRITE(6,189) ITRPR
      GO TO 500
365      IF(LSTEP.EQ.1) GO TO 367
      WRITE(6,266) ITRMAX,LSTEP,NO
      WRITE(6,188) (AVB(M),M=1,MAXM)
      GO TO 500
367      WRITE(6,273)
      GO TO 500
C*****
71      FORMAT(20X,I3,4X,4E20.6)
112      FORMAT(///17X,12H STATION 20H B STIFFNESS 20H D ST
1 IFNESS 23H D PRIME //)
126      FORMAT(///5X,29H THE INITIAL CONDITIONS FOR N=13,8H FOLLOW//)
127      FORMAT(19X,7H STATION,3X,20H U M S DOT 20H V DOT
1 20H W DOT 20H)
129      FORMAT(///19X,7H STATION,3X,20H U M S DOT 20H V DOT
1 20H W DOT 20H)
188      FORMAT(/// THE MAXIMUM VBAR FOR EACH MODE IS,10E11.4)
189      FORMAT(, THE MAXIMUM NUMBER OF ITERATIONS TAKEN IS ,I3)
266      FORMAT(1H1,35H THE SOLUTION DID NOT CONVERGE IN I3,24H ITERATIONS
00002410
00002420
00002430
00002440
00002450
00002460
00002470
00002480
00002490
00002500
00002510
00002520
00002530
00002540
00002550
00002560
00002570
00002580
00002590
00002600
00002610
00002620
00002630
00002640
00002650
00002660
00002670
00002680
00002690
00002700
00002710
00002720
00002730
00002740
00002750
00002760
00002770
00002780
00002790
00002800
00002810
00002820
00002830
00002840
00002850
00002860
00002870
00002880

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```

1 AT TIME STEP15,21H. END PROBLEM NUMBER14,1H.)
271 FORMAT(1H,79H THE MAXIMUM NUMBER OF TIME STEPS HAVE BEEN
1 TAKEN. END PROBLEM NUMBER14)
273 FORMAT(1H,69H THE SOLUTION DID NOT CONVERGE FOR THE FIRST
IT TIME INCREMENT./11X,71HLOOK FOR AN ERROR IN THE INPUT DATA, OR TRY A SMALLER VALUE FOR DELTA.)
810 FORMAT(1H,5X,15H STATION 16H RADIUS 16H GAMMA
1 16H OMEGA S 16H DEOMEGA S 16H
2 MASS //)
813 FORMAT(8X,I3,9X,6E16.4)
8888 FORMAT(' ',110,'EXECUTING IN SUBROUTINE "DYNAMIC"')
500 RETURN
END
00002890
000002900
00002910
000002920
000002930
000002940
00002950
00002960
00002970
00002980
00002990
00003000
00003010

```

```

SUBROUTINE OUTPUT(I MODE)
THIS SUBROUTINE PREPARES THE PRINTOUT MATERIAL. EVERY IPRINT *
CONVERGED SOLUTION IS PRINTED. THE FOURIER COEFFICIENTS OF THE *
INPLANE FORCES, MERIDIONAL TRANSVERSE FORCE, CIRCUMFERENTIAL *
BENDING MOMENT, TWISTING MOMENT AND ROTATIONS CAN BE COMPUTED *
AND PRINTED WITH THE SOLUTION Z FOR THE FOURIER COEFFICIENTS *
OF THE THREE DISPLACEMENTS AND MERIDIONAL BENDING MOMENT. THIS *
OUTPUT MATERIAL IS CONVERTED FROM DIMENSIONLESS FORM TO DIMEN- *
SIONAL FORM HERE. 1. IFREQ+1, 2IFREQ+1, ETC. THIS SUBROUTINE ALSO PERFORMS THE *
SUMMATION PROCESS FOR COMPUTING THE TOTAL VALUES OF THE FORCES, *
MOMENTS, DISPLACEMENTS AND ROTATIONS AT THE NTHMAX POSITIONS *
AROUND THE CIRCUMFERENCE PRESCRIBED IN THE INPUT DATA. *
DATA TO BE PLOTTED IS PREPARED HERE, IF REQ'D *
IMPLICIT LOGICAL*1 ($) *
REAL NU, MT, MX, MTH, MXT, MTS, KX, KT, KXT, LAM, LAM2, MASS *
COMMON /IBL2/ N(10), MNINIT *
COMMON /IBL3/ M0, M1, M2, M3 *
COMMON /IBL4/ KMAX, KL *
COMMON /IBL5/ IBCINL, IBCFNL *
COMMON /IBL7/ MNMAXO, MAXD(10), MAXS(10), MAXSY(10), IS(10,10),
00000010
00000020
00000030
00000040
00000050
00000060
00000070
00000080
00000090
00000100
00000110
00000120
00000130
00000140
00000150
00000160
00000170
00000180
00000190
00000200
00000210
00000220
00000230

```



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1 COMMON /IBL8/ JS(10,10), ID(10,10), JD(10,10), IJS(10)
COMMON /IBL10/ LSTEP, ITR
COMMON /IBL12/ IFREQ, NTHMAX
COMMON /IBL13/ KMAX1, KMAX2, NCONV
COMMON /IBL4/ ITRMAX, LSMAK
COMMON /BL4/ P(4,4,200), X(4,200), ZF1M(4,4,10), ZF2M(4,4,10),
1 ZF3M(4,4,10), ZF4M(4,4,10)
COMMON /BL5/ TT(10), MT(10), DT(10), DMT(10)
COMMON /BL6/ Z(4,220), SOE, QSE, ALOAD
COMMON /BL7/ D1, S1
COMMON /BL8/ R(200), GAM(200), OMT(200)
COMMON /BL10/ PHIX(10), PHIT(10), PHI(10)
COMMON /BL11/ OMXI(200), PHEE, TO, T2
COMMON /BL12/ TDLI, TDEL
COMMON /BL14/ LAM2, LSD18, LSD1N
COMMON /BL15/ NU, UI(10), VI(10), W1(10), V2(10), U2(10), W2(10), U3(10),
1 V3(10), W3(10)
COMMON /BL17/ DEL
COMMON /BL19/ TH(36)
COMMON /BL20/ DEOMX(200)
COMMON /BL27/ BX3(10), BXT3(10), BE3(10)
COMMON /BL31/ DELSQ, EXT1(10)
COMMON /BL32/ TKN, ELAST, CHAR, SIGO
COMMON /BL100/ TEOO, $DYNMC
COMMON /BL101/ ZO(4,220), Z2(4,220), Z3(4,220), DELSD
COMMON /BL102/ DELOAD
COMMON /BL103/ MASS(200)
COMMON /BL110/ TX(10), TTH(10), TXT(10), MX(10), MTH(10), MXT(10),
1 QS(10)
COMMON /BL111/ ABZ, ABZO, ABZN, ABZ3, DD2
COMMON /BLPLOT/ IRADII, IGAMMA, IOMEGS, IOMEGT, IDEOMS, IBSTIF, IDSTIF,
1 IBBSTF, IODSTF, IPR, IPS, IPT, ITT, IMT, IDIT, IDMT, INS,
2 INTH, INSTH, IQS, IMS, IMTH, IMSTH, IU, IV, IW, IPHIS,
3 IPHIT, IPHI, $PLOTS, $MODAL
COMMON /BLPLT1/ XRADII(100), YGAMMA(100), YOMEGS(100), YOMEGT(100),
1 YDEOMS(100), YBSTIF(100), YDSTIF(100), YBBSTF(100),
2 YDDSTF(100), YPR(100), YPS(100), YPT(100), YTT(100),
3 YMT(100), YDTT(100), YDMT(100), YNS(100), YNTH(100),
4 YNSTH(100), YQS(100), YMS(100), YMTH(100), YMSTH(100),
5 YU(100), YV(100), YW(100), YPHIS(100), YPHIT(100),
6 YPHI(100), XSTATN(100)
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DTI=TI*TEEO
WRITE(6,151) LSTEP, TI, DTI, ITR
182 LAM=TKN/CHAR
ENL=1.
ABZ=SIGO*TKN
ABZ3=ABZ*TKN*TKN/CHAR
ABZN=CHAR*SIGJ/ELAST
IF(ITRMAX.EQ.1) ENL=0.
DD2=1.-NU**2
D2I=1./DD2
DPI=1./SI
DNI=1./DI
TDLSQL=.5/DELSQ
1 ICHCK1=IABS(INS)+IABS(INTH)+IABS(IQS)+IABS(IMS)
+IABS(IMTH)+IABS(IMSTH)
1 ICHCK2=IABS(IU)+IABS(IV)+IABS(IW)+IABS(IPHIS)+IABS(IPHIT)
+IABS(IPHI)
IF(NTHMAX.EQ.0) GO TO 991
DO 21 NTH=1, NTHMAX
DO 1 MN=1, MNMAX
I1=1+(MN-1)*KMAX2
I2=I1+1
U1(MN)=Z(1, I1)
U2(MN)=Z(1, I2)
V1(MN)=Z(2, I1)
V2(MN)=Z(2, I2)
W1(MN)=Z(3, I1)
W2(MN)=Z(3, I2)
1 THET=TH(NTH)
WRITE(6,116) THET
DO 121 K=1, KMAX
K1=K+1
CALL BDB(K, BS, DB, DS, DD)
IF(K.EQ.1.AND.IBCINL.LT.0) CALL POLE(K)
IF(K.EQ.1.AND.IBCINL.LT.0) GO TO 999
IF(K.EQ.KMAX.AND.IBCFNL.LT.0) CALL POLE(K)
IF(K.EQ.KMAX.AND.IBCFNL.LT.0) GO TO 999
CALL PHIBET(K)
DEX=DEOMX(K)
RRA=1./R(K)
OX=OMXI(K)
OT=OMT(K)
GA=GAM(K)
DOXT=OX-OT
GDO=GA*DOXT
DD2D=DD2*DS
DO 3 MN=1, MNMAX
EN=N(MN)

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ENR=EN*RRRA
CALL TLOAD(K)
TTS=TT(MN)*ALOAD
EX=(U3(MN)-U1(MN))*TDLI+OX*W2(MN)+ENL*OSE*(BX3(MN)+BE3(MN))
ET=ENR*V2(MN)+GA*U2(MN)+OT*W2(MN)+ENL*OSE*(BT3(MN)+BE3(MN))
EXT=.5*((V3(MN)-V1(MN))*TDLI-ENR*U2(MN)-GA*V2(MN)+ENL*SOE*BT3(MN))
1)
KT=ENR*PHIT(MN)+GA*PHIX(MN)
KXT=.5*(ENR*(-PHIX(MN)-GA*W2(MN)+(W3(MN)-W1(MN))*TDLI)+GDO*V2(MN)
+OT*(V3(MN)-V1(MN))*TDLI-GA*PHIT(MN)-DOXT*PHI(MN))
TX(MN)=BS*(EX+NU*ET)-TTS
TTH(MN)=BS*(ET+NU*EX)-TTS
TXT(MN)=BS*D1*EXT
MK1=K1+(MN-1)*KMAX2
MX(MN)=Z(4,MK1)
MTH(MN)=NU*MX(MN)+DD2D*KT-D1*MT(MN)*ALOAD
MXT(MN)=DS*D1*KXT
MK11=MK1+1
MK1=MK1-1
QS(MN)=SIGO*TKN*LAM2*(GA*MX(MN)+(Z(4,MK11)-Z(4,MK1))*TDLI
+ENR*MXT(MN)-GA*MTH(MN))
1)
MX(MN)=MX(MN)*ABZ3
MTH(MN)=MTH(MN)*ABZ3
MXT(MN)=MXT(MN)*ABZ3
TX(MN)=TX(MN)*ABZ
TTH(MN)=TTH(MN)*ABZ
TXT(MN)=TXT(MN)*ABZ
PHIX(MN)=PHIX(MN)*ABZO
PHIT(MN)=PHIT(MN)*ABZO
PHI(MN)=PHI(MN)*ABZO
U1(MN)=U2(MN)
U2(MN)=U3(MN)
V1(MN)=V2(MN)
V2(MN)=V3(MN)
W1(MN)=W2(MN)
W2(MN)=W3(MN)
FK=K-1
FIFREQ=IFREQ
KTST=(K-1)/IFREQ
FKTST=KTST
FKTEST=FK/FIFREQ-FKTST
IF(K.EQ.1.OR.K.EQ.KMAX) GO TO 999
IF(FKTEST.NE.0.) GO TO 2
999
X(1,K)=0.
X(2,K)=0.
X(3,K)=0.
X(4,K)=0.
PTF(K)=0.
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PF(K)=0.
AMX=0.
AMTH=0.
AMXTH=0.
ANX=0.
ANTH=0.
ANXTH=0.
AQS=0.
DO 72 MN=1,MNMAXO
EN=N(MN)
FC=EN*THET
SN=SIN(FC)
CS=COS(FC)
X(1,K)=X(1,K)+U1(MN)*CS*ABZN
X(2,K)=X(2,K)+V1(MN)*SN*ABZN
X(3,K)=X(3,K)+W1(MN)*CS*ABZN
X(4,K)=X(4,K)+PHIX(MN)*CS
PTF(K)=PTF(K)+PHIT(MN)*SN
AMX=AMX+MX(MN)*CS
AMTH=AMTH+MTH(MN)*CS
AMXTH=AMXTH+MXT(MN)*SN
ANX=ANX+TX(MN)*CS
ANTH=ANTH+TTH(MN)*CS
AQS=AQS+QS(MN)*CS
ANXTH=ANXTH+TXT(MN)*SN
PF(K)=PF(K)+PHI(MN)*SN
CONTINUE
72
429 IF(K.EQ.1) WRITE(6,117)
IF((K.EQ.1.AND.IBCINL.LT.0).OR.(K.EQ.KMAX.AND.IBCFNL.LT.0))
1 GO TO 221
GO TO 221
220 WRITE (6,1181) K,ANX,ANTH,ANXTH,AMX,AMTH,AMXTH
GO TO 1354
221 WRITE(6,118) K,ANX,ANTH,ANXTH,AQS,AMX,AMTH,AMXTH
1354 IF ($MODAL.OR.(ICHECK1.EQ.0)) GO TO 2
YNS(K)=ANX
YNTH(K)=ANTH
YNSTH(K)=ANXTH
YQS(K)=AQS
YMS(K)=AMX
YMTH(K)=AMTH
YMSTH(K)=AMXTH
CONTINUE
CONTINUE
2
121 DO 663 K=1,KMAX
FK=K-1
FIIFREQ=IFREQ
KTST=(K-1)/IFREQ

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FKTST=K1ST
FKTEST=FK/FIFREQ-FK1ST
IF(K.EQ.1.OR.K.EQ.KMAX) GO TO 661
IF(FKTEST.NE.0.) GO TO 658
661 IF(K.EQ.1) WRITE(6,217)
      WRITE(6,218) K,X(1,K),X(2,K),X(3,K),X(4,K),PTF(K),PF(K)
      IF ($MODAL.OR.(ICHECK2.EQ.0)) GO TO 658
      YU(K)=X(1,K)
      YV(K)=X(2,K)
      YW(K)=X(3,K)
      YPHIS(K)=X(4,K)
      YPHIT(K)=PTF(K)
      YPHI(K)=PF(K)
      DO 659 I=1,4
658 X(I,K)=0.
659 CONTINUE
660 IF ($PLOTS.AND..NOT.$MODAL.AND.((ICHECK1.GT.0).OR.(ICHECK2.GT.0)))
      1 CALL PLOT2(NTH)
      21 CONTINUE
      IF(IMODE.LE.0) RETURN
991 DO 534 MN=1,MNMAX0
      WRITE(6,749) N(MN)
      DO 521 MM=1,MNMAX0
      I1=1+(MM-1)*KMAX2
      I2=I1+1
      U1(MM)=Z(1,I1)
      U2(MM)=Z(1,I2)
      V1(MM)=Z(2,I1)
      V2(MM)=Z(2,I2)
      W1(MM)=Z(3,I1)
      W2(MM)=Z(3,I2)
521 CONTINUE
      DO 445 K=1, KMAX
      K1=K+1
      CALL BDB(K,BS,DB,DS,DD)
      IF(K.EQ.1.AND.IBCINL.LT.0) CALL POLE(K)
      IF(K.EQ.KMAX.AND.IBCFNL.LT.0) CALL POLE(K)
      TXZ=TX(MN)
      TTHZ=TTH(MN)
      TXTZ=TX(MN)
      AMXZ=MX(MN)
      AMTHZ=MTH(MN)
      AMXTZ=MX(MN)
      QSZ=QS(MN)
      X(1,K)=PHI X(MN)
      X(2,K)=PHI T(MN)
      X(3,K)=PHI(MN)
      IF(K.EQ.1.AND.IBCINL.LT.0) GO TO 583

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IF(K.EQ.KMAX.AND.IBCFNL.LT.0) GO TO 583
CALL PHIBET(K)
DEX=DEOMX(K)
RRA=1./R(K)
OX=OMXI(K)
OT=OMT(K)
GA=GAM(K)
DOXT=OX-OT
GDO=GA*DOXT
DD2D=DD2*DS
EN=N(MN)
ENR=EN*RA
CALL TLOAD(K)
TTS=TT(MN)*ALJAD
EX=(U3(MN)-U1(MN))*TDLI+OX*W2(MN)+ENL*OSE*(BX3(MN)+BE3(MN))
ET=ENR*V2(MN)+GA*U2(MN)+OT*W2(MN)+ENL*OSE*(BT3(MN)+BE3(MN))
EXT=.5*((V3(MN)-V1(MN))*TDLI-ENR*U2(MN)-GA*V2(MN)+ENL*SOE*BX3(MN)
1)
KT=ENR*PHIT(MN)+GA*PHIX(MN)
KXT=.5*(ENR*(-PHIX(MN)-GA*W2(MN)+(W3(MN)-W1(MN))*TDLI)+GDO*V2(MN)
1 +OT*(V3(MN)-V1(MN))*TDLI-GA*PHIT(MN)-DOXT*PHI(MN))
TXZ=(BS*(EX+NU*ET)-TTS)*ABZ
TTHZ=(BS*(ET+NU*EX)-TTS)*ABZ
TXTZ=BS*DI*EXT*ABZ
MK1=K1+(MN-1)*KMAX2
AMXZ=Z(4,MK1)
AMTHZ=NU*AMXZ+DD2D*KT-DI*MT(MN)*ALOAD
AMXTZ=DS*DI*KXT
MK11=MK1+1
MKK1=MK1-1
QSZ=SIGO*TKN*LAM2*(GA*AMXZ+(Z(4,MK11)-Z(4,MK1))*TDLI+ENR*AMXTZ
1 -GA*AMTHZ)
AMXZ=AMXZ*ABZ3
AMTHZ=AMTHZ*ABZ3
AMXTZ=AMXTZ*ABZ3
X(1,K)=PHIX(MN)*ABZO
X(2,K)=PHIT(MN)*ABZO
X(3,K)=PHI(MN)*ABZO
DO 533 MM=1,MNMA XO
U1(MM)=U2(MM)
U2(MM)=U3(MM)
V1(MM)=V2(MM)
V2(MM)=V3(MM)
W1(MM)=W2(MM)
W2(MM)=W3(MM)
FK=K-1
FIIFREQ=IFREQ
KTST=(K-1)/IFREQ
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FKTST=KTST
FKTEST=FK/FIFREQ-FKTST
IF(K.EQ.1.OR.K.EQ.KMAX) GO TO 583
IF(FKTEST.NE.0.) GO TO 445
583 CONTINUE
IF(K.EQ.1) WRITE(6,117)
IF((K.EQ.1.AND.IBCINL.LT.0).OR.(K.EQ.KMAX.AND.IBCFNL.LT.0))
1 GO TO 4444
GO TO 4445
4444 WRITE(6,1181) K, TXZ, TTHZ, TXTZ, AMXZ, AMTHZ, AMXTZ
GO TO 4446
4445 WRITE(6,118) K, TXZ, TTHZ, TXTZ, QSZ, AMXZ, AMTHZ, AMXTZ
4446 IF(.NOT.$PLOTS.OR..NOT.$MODAL.OR.((ICHECK1.EQ.0)) GO TO 445
YNS(K)=TXZ
YNTH(K)=TTHZ
YNSTH(K)=TXTZ
YQS(K)=QSZ
YMS(K)=AMXZ
YMTH(K)=AMTHZ
YMSTH(K)=AMXTZ
CONTINUE
445 WRITE(6,217)
446 DO 447 K=1,KMAX
FK=K-1
FIFREQ=IFREQ
KTST=(K-1)/IFREQ
FKTST=KTST
FKTEST=FK/FIFREQ-FKTST
IF(K.EQ.1.OR.K.EQ.KMAX) GO TO 593
IF(FKTEST.NE.0.) GO TO 446
593 KZ=K+1+(MN-1)*KMAX2
UP=Z(1,KZ)*ABZN
VP=Z(2,KZ)*ABZN
WP=Z(3,KZ)*ABZN
WRITE(6,218) K, UP, VP, WP, X(1,K), X(2,K), X(3,K)
IF(.NOT.$PLOTS.OR..NOT.$MODAL.OR.((ICHECK2.EQ.0)) GO TO 447
YU(K)=UP
YV(K)=VP
YW(K)=WP
YPHIS(K)=X(1,K)
YPHIT(K)=X(2,K)
YPHI(K)=X(3,K)
447 CONTINUE
IF ($PLOTS.AND.$MODAL.AND.((ICHECK1.GT.0).OR.(ICHECK2.GT.0)))
1 CALL PLOT2(1)
534 CONTINUE
C*****
101 FORMAT('1', '
THE LOAD STEP NUMBER IS ', I2, '
THE L00003490

```







```

C*****YPHI(100),XSTATN(100)*****00000190
6*****NGKMAX=-KMAX00000191
  IF ($MODAL) GO TO 121
  IF (INS.EQ.0) GO TO 4
  WRITE (6,1000)
  IF (INS.GT.0) CALL PLOTIT (XSTATN,YNS,KMAX,0)
  IF (INS.LT.0) CALL PLOTIT (XSTATN,YNS,NGKMAX,0)
  WRITE (6,1001) TH(NTH)
  IF (INTH.EQ.0) GO TO 5
  WRITE (6,1000)
  IF (INTH.GT.0) CALL PLOTIT (XSTATN,YNTH,KMAX,0)
  IF (INTH.LT.0) CALL PLOTIT (XSTATN,YNTH,NGKMAX,0)
  WRITE (6,1002) TH(NTH)
  IF (INSTH.EQ.0) GO TO 6
  WRITE (6,1000)
  IF (INSTH.GT.0) CALL PLOTIT (XSTATN,YNSTH,KMAX,0)
  IF (INSTH.LT.0) CALL PLOTIT (XSTATN,YNSTH,NGKMAX,0)
  WRITE (6,1003) TH(NTH)
  IF (IQS.EQ.0) GO TO 7
  WRITE (6,1000)
  IF (IQS.GT.0) CALL PLOTIT (XSTATN,YQS,KMAX,0)
  IF (IQS.LT.0) CALL PLOTIT (XSTATN,YQS,NGKMAX,0)
  WRITE (6,1004) TH(NTH)
  IF (IMS.EQ.0) GO TO 8
  WRITE (6,1000)
  IF (IMS.GT.0) CALL PLOTIT (XSTATN,YMS,KMAX,0)
  IF (IMS.LT.0) CALL PLOTIT (XSTATN,YMS,NGKMAX,0)
  WRITE (6,1005) TH(NTH)
  IF (IMTH.EQ.0) GO TO 9
  WRITE (6,1000)
  IF (IMTH.GT.0) CALL PLOTIT (XSTATN,YMTH,KMAX,0)
  IF (IMTH.LT.0) CALL PLOTIT (XSTATN,YMTH,NGKMAX,0)
  WRITE (6,1006) TH(NTH)
  IF (IMSTH.EQ.0) GO TO 1211
  WRITE (6,1000)
  IF (IMSTH.GT.0) CALL PLOTIT (XSTATN,YMSTH,KMAX,0)
  IF (IMSTH.LT.0) CALL PLOTIT (XSTATN,YMSTH,NGKMAX,0)
  WRITE (6,1007) TH(NTH)
  IF (IU.EQ.0) GO TO 10
  WRITE (6,1000)
  IF (IU.GT.0) CALL PLOTIT (XSTATN,YU,KMAX,0)
  IF (IU.LT.0) CALL PLOTIT (XSTATN,YU,NGKMAX,0)
  WRITE (6,1010) TH(NTH)
  IF (IV.EQ.0) GO TO 11
  WRITE (6,1000)
  IF (IV.GT.0) CALL PLOTIT (XSTATN,YV,KMAX,0)
  IF (IV.LT.0) CALL PLOTIT (XSTATN,YV,NGKMAX,0)
  1211
  10
00000200
00000210
00000220
00000230
00000240
00000250
00000260
00000270
00000280
00000290
00000300
00000310
00000320
00000330
00000340
00000350
00000360
00000370
00000380
00000390
00000400
00000410
00000420
00000430
00000440
00000450
00000460
00000470
00000480
00000490
00000500
00000510
00000520
00000530
00000540
00000550
00000560
00000570
00000580
00000590
00000600
00000610
00000620
00000630
00000640
00000650

```





```

11 WRITE (6,1009) TH(NTH)
   IF (IW.EQ.0) GO TO 12
   WRITE (6,1030)
   IF (IW.GT.0) CALL PLOTIT (XSTATN,YW,KMAX,0)
   IF (IW.LT.0) CALL PLOTIT (XSTATN,YW,NGKMAX,0)
   WRITE (6,1008) TH(NTH)
12 IF (IPHS.EQ.0) GO TO 13
   WRITE (6,1000)
   IF (IPHS.GT.0) CALL PLOTIT (XSTATN,YPHIS,KMAX,0)
   IF (IPHS.LT.0) CALL PLOTIT (XSTATN,YPHIS,NGKMAX,0)
   WRITE (6,1011) TH(NTH)
13 IF (IPHIT.EQ.0) GO TO 14
   WRITE (6,1000)
   IF (IPHIT.GT.0) CALL PLOTIT (XSTATN,YPHIT,KMAX,0)
   IF (IPHIT.LT.0) CALL PLOTIT (XSTATN,YPHIT,NGKMAX,0)
   WRITE (6,1012) TH(NTH)
14 IF (IPHI.EQ.0) GO TO 21
   WRITE (6,1000)
   IF (IPHI.GT.0) CALL PLOTIT (XSTATN,YPHI ,KMAX,0)
   IF (IPHI.LT.0) CALL PLOTIT (XSTATN,YPHI ,NGKMAX,0)
   WRITE (6,1013) TH(NTH)
21 RETURN
121 IF (INS.EQ.0) GO TO 15
   WRITE (6,1000)
   IF (INS.GT.0) CALL PLOTIT (XSTATN,YNS,KMAX,0)
   IF (INS.LT.0) CALL PLOTIT (XSTATN,YNS,NGKMAX,0)
   WRITE (6,2001)
15 IF (INTH.EQ.0) GO TO 16
   WRITE (6,1000)
   IF (INTH.GT.0) CALL PLOTIT (XSTATN,YNTH,KMAX,0)
   IF (INTH.LT.0) CALL PLOTIT (XSTATN,YNTH,NGKMAX,0)
   WRITE (6,2002)
16 IF (INSTH.EQ.0) GO TO 17
   WRITE (6,1000)
   IF (INSTH.GT.0) CALL PLOTIT (XSTATN,YNSTH,KMAX,0)
   IF (INSTH.LT.0) CALL PLOTIT (XSTATN,YNSTH,NGKMAX,0)
   WRITE (6,2003)
17 IF (IQS.EQ.0) GO TO 18
   WRITE (6,1000)
   IF (IQS.GT.0) CALL PLOTIT (XSTATN,YQS,KMAX,0)
   IF (IQS.LT.0) CALL PLOTIT (XSTATN,YQS,NGKMAX,0)
   WRITE (6,2004)
18 IF (IMS.EQ.0) GO TO 19
   WRITE (6,1000)
   IF (IMS.GT.0) CALL PLOTIT (XSTATN,YMS,KMAX,0)
   IF (IMS.LT.0) CALL PLOTIT (XSTATN,YMS,NGKMAX,0)
   WRITE (6,2005)
19 IF (IMTH.EQ.0) GO TO 22

```

```

00000660
00000670
00000680
00000690
00000700
00000710
00000720
00000730
00000740
00000750
00000760
00000770
00000780
00000790
00000800
00000810
00000820
00000830
00000840
00000850
00000860
00000870
00000880
00000890
00000900
00000910
00000920
00000930
00000940
00000950
00000960
00000970
00000980
00000990
00001000
00001010
00001020
00001030
00001040
00001050
00001060
00001070
00001080
00001090
00001100
00001110
00001120
00001130

```









```

1004 FORMAT ('0',T10,'EFFECTIVE SHEAR VS STATN, MERIDIAN AT THETA = ',00001620
1F10.5, RADIAN')
1005 FORMAT ('0',T10,'S"--BENDING MOMENT VS STATN, MERIDIAN AT THETA =00001633
1,F10.5, RADIAN')
1006 FORMAT ('0',T10,'THETA-BENDING MOMENT VS STATN, MERIDIAN AT THETA00001640
1=F10.5, RADIAN')
1007 FORMAT ('0',T10,'S-THETA BENDING MOMENT VS STATN, MERIDIAN AT THE00001660
1TA =,F10.5, RADIAN')
1008 FORMAT ('0',T10,'NORMAL DEFLECTION VS STATN, MERIDIAN AT THETA = 00001680
1,F10.5, RADIAN')
1009 FORMAT ('0',T10,'CIRCUMFERENTIAL DEFLECTION VS STATN, MERIDIAN AT00001700
1THETA =,F10.5, RADIAN')
1010 FORMAT ('0',T10,'MERIDIONAL DEFLECTION VS STATN, MERIDIAN AT THET00001720
1A =,F10.5, RADIAN')
1011 FORMAT ('0',T10,'MERIDIONAL ROTATION VS STATN, MERIDIAN AT THETA 00001750
1=F10.5, RADIAN')
1012 FORMAT ('0',T10,'CIRCUMFERENTIAL ROTATION VS STATN, MERIDIAN AT T00001780
1THETA =,F10.5, RADIAN')
1013 FORMAT ('0',T10,'MERIDIO-CIRCUMFERENTIAL ROTATION VS STATN, MERID00001800
1IAN AT THETA =,F10.5, RADIAN')
2001 FORMAT ('0',T10,'S"--MEMBRANE FORCE VS STATION')
2002 FORMAT ('0',T10,'THETA"-MEMBRANE FORCE VS STATION')
2003 FORMAT ('0',T10,'S-THETA" MEMBRANE FORCE VS STATION')
2004 FORMAT ('0',T10,'EFFECTIVE SHEAR VS STATION')
2005 FORMAT ('0',T10,'S"--BENDING MOMENT VS STATION')
2006 FORMAT ('0',T10,'THETA-BENDING MOMENT VS STATION')
2007 FORMAT ('0',T10,'S-THETA BENDING MOMENT VS STATION')
2008 FORMAT ('0',T10,'NORMAL DEFLECTION VS STATION')
2009 FORMAT ('0',T10,'CIRCUMFERENTIAL DEFLECTION VS STATION')
2010 FORMAT ('0',T10,'MERIDIONAL DEFLECTION VS STATION')
2011 FORMAT ('0',T10,'MERIDIONAL ROTATION VS STATION')
2012 FORMAT ('0',T10,'CIRCUMFERENTIAL ROTATION VS STATION')
2013 FORMAT ('0',T10,'MERIDIO-CIRCUMFERENTIAL ROTATION VS STATION')
C*****
END
00001950
00001960

```



```

SUBROUTINE FLYNVY
WRITE (6,11)
WRITE (6,1)
WRITE (6,2)
WRITE (6,3)
WRITE (6,4)
WRITE (6,5)
WRITE (6,6)
WRITE (6,7)
WRITE (6,8)
WRITE (6,9)
WRITE (6,10)
WRITE (6,11)
WRITE (6,12)
WRITE (6,13)
WRITE (6,14)
WRITE (6,15)
WRITE (6,16)
WRITE (6,17)
WRITE (6,18)
WRITE (6,19)
WRITE (6,20)
WRITE (6,21)
WRITE (6,22)
WRITE (6,23)
WRITE (6,24)
WRITE (6,25)
WRITE (6,26)
WRITE (6,27)
WRITE (6,28)
WRITE (6,29)
WRITE (6,30)
WRITE (6,31)
WRITE (6,32)
WRITE (6,33)
WRITE (6,34)
WRITE (6,35)
WRITE (6,36)
WRITE (6,37)
WRITE (6,38)
WRITE (6,39)
WRITE (6,40)
111 FORMAT ('1',T11)
111 FORMAT (XXX)
211 FORMAT (XXXX)
311 FORMAT ('1',T11)

```



```

1   XXX   XXX')
4   FORMAT (' ',T11,'
1   XXX   XXX')
5   FORMAT (' ',T11,'
1   FORMAT (X@XXX')
6   FORMAT (' ',T11,'XXXXXXXXXXXXXXXXXXXXX
1   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
2   XX')
7   FORMAT (' ',T11,'XXXXXXXXXX00XXXXXX00XXXXXX0X
1   XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXX
2)
8   FORMAT (' ',T11,'
1   XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX0X
9   FORMAT (' ',T11,'
1   XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX')
10  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX
11  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX')
12  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX
13  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX
14  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX
15  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX
16  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX
17  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX
18  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX
19  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX
20  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX
21  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX
22  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX
23  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX
24  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX
25  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX
26  XXXXXXXXXXXXXXXXXXXXXXXX00XXXXXX00XXXXXX00XXXXXX

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161



```

SUBROUTINE FORCE(K)
C*****
C THIS SUBROUTINE COMPUTES THE GEE VECTOR IN EQUATION (28) OF
C REF. 3, AND THE X VECTOR IN EQUATION (29A) OF REF. 3 FOR A GIVEN MER-
C IDIONAL STATION K. THE VECTOR 'GEES' IS THE NONLINEAR VALUE OF 'GEE'
C AT STATION 1.
C*****
IMPLICIT LOGICAL*1 ($)
REAL NU,MT,LAM2,MASS,MAS
COMMON /IBL1/ MNMAX
COMMON /IBL2/ N(10),MNINIT
COMMON /IBL4/ KMAX,KL
COMMON /IBL8/ LSTEP,ITR
COMMON /IBL12/ KMAX1,KMAX2,NCONV
COMMON /IBL13/ ITRMAX,LSMAX
COMMON /BL3/ PR(10),PX(10),PT(10)
COMMON /BL4/ P(4,4,200),X(4,200),ZF1M(4,4,10),ZF2M(4,4,10),
1 ZF3M(4,4,10),ZF4M(4,4,10)
COMMON /BL5/ TT(10),MT(10),DT(10),DMT(10)
COMMON /BL6/ Z(4,220),SOE,OSE,ALOAD
COMMON /BL7/ D1,S1
COMMON /BL8/ R(200),GAM(200),OMT(200)
COMMON /BL9/ RFFS(4,10),ELIS(4),GEES(4,10)
COMMON /BL11/ OMXI(200),PHEE,T0,T2
COMMON /BL12/ TDLI,TDEL
COMMON /BL14/ LAM2,LSDI8,LSDDIN
COMMON /BL15/ NU,U1(10),V1(10),W1(10),V2(10),U2(10),W2(10),U3(10),
1 V3(10),W3(10)
COMMON /BL17/ DEL
COMMON /BL24/ DL(4,4,10),DG(4,4,10),DF(4,4,10)
COMMON /BL27/ BX3(10),BT3(10),BXT3(10),BE3(10)
COMMON /BL28/ EXX3(10),ETT3(10),ETX3(10),EXT3(10),EX3(10),ET3(10)
COMMON /BL29/ BX1(10),BT1(10),BXT1(10),BE1(10),BX2(10),BT2(10),
1 BXT2(10),BE2(10)
COMMON /BL30/ EXX1(10),ETT1(10),ETX1(10),EXT1(10),EX1(10),ET1(10),EXX2(10),
1 ETT2(10),ETT2(10),EXT2(10),EX2(10),ET2(10)
COMMON /BL31/ DELSQ,EXT1(10)
COMMON /BL34/ DEE(4,4,200),DST(4,4,200)
COMMON /BL100/ TEE0,$DYNMC
COMMON /BL101/ ZO(4,220),Z2(4,220),Z3(4,220),DELSO
COMMON /BL102/ DELOAD
COMMON /BL103/ MASS(200)
DIMENSION GEE(4)
C*****
FDIFF(A,B,C)=(-1.5*A+2.*B-.5*C)/DEL
RS=R(K)
RR=1./RS
GA=GAM(K)

```



```

OX=OMXI(K)
OT=OMT(K)
DL2=D1*LAM2
CALL BDB(K,BS,DBS,D,DD)
CALL PLOAD(K)
CALL TLOAD(K)
MAS=MASS(K)
DO 4 M=1,MNMAX
  IZ=K+1+(M-1)*KMAX2
  IK=K+(M-1)*KMAX
  IK1=IK-1
  EN=N(M)
  ENR=EN*RR
  EMT=MT(M)
  GEE(1) = (-PX(M)+DT(M)-DL2*GA*OX*EMT)*TDEL*ALOAD
1  + MAS*(-5.*ZO(1,IZ)+4.*Z2(1,IZ)-Z3(1,IZ))*TDEL/DELS D
1  GEE(2) = (-PT(M)-ENR*TT(M)-DL2*ENR*OT*EMT)*TDEL*ALOAD
1  + MAS*(-5.*ZO(2,IZ)+4.*Z2(2,IZ)-Z3(2,IZ))*TDEL/DELS D
1  GEE(3) = (-PR(M)-(OX+OT)*TT(M)-DL2*(GA*DMT(M)-(OX*OT-ENR**2)
1  *MT(M)))*TDEL*ALOAD
1  + MAS*(-5.*ZO(3,IZ)+4.*Z2(3,IZ)-Z3(3,IZ))*TDEL/DELS D
1  GEE(4) = MT(M)*TDEL*ALOAD
  IF(I*TRMAX.EQ.1) GO TO 50
  IF(K.GT.1) GO TO 6
  BX2T=BX1(M)
  BT2T=BT1(M)
  BX12T=BX11(M)
  BE2T=BE1(M)
  EXX2T=EXX1(M)
  ET12T=ET1(M)
  ETX2T=ETX1(M)
  EX2T=EX1(M)
  ET2T=ET1(M)
  DBX= FDIFF(BX2T,BX2(M),BX3(M))
  DBT= FDIFF(BT2T,BT2(M),BT3(M))
  DBX2T= FDIFF(BX12T,BX12(M),BX13(M))
  DBE= FDIFF(BE2T,BE2(M),BE3(M))
  DET= FDIFF(ET2T,ET2(M),ET3(M))
  DEX= FDIFF(ETX2T,ETX2(M),ETX3(M))
  DEXX= FDIFF(EXX2T,EXX2(M),EXX3(M))
  DETX= FDIFF(ETX2T,ETX2(M),ETX3(M))
  GO TO 7
6  IF(K.LT.KMAX) GO TO 8
  BX2T=BX3(M)
  BT2T=BT3(M)
  BX12T=BX13(M)
  BE2T=BE3(M)

```



00000960  
 00000970  
 00000980  
 00000990  
 00001000  
 00001010  
 00001020  
 00001030  
 00001040  
 00001050  
 00001060  
 00001070  
 00001080  
 00001090  
 00001100  
 00001110  
 00001120  
 00001130  
 00001140  
 00001150  
 00001160  
 00001170  
 00001180  
 00001190  
 00001200  
 00001210  
 00001220  
 00001230  
 00001240  
 00001250  
 00001260  
 00001270  
 00001280  
 00001290  
 00001300  
 00001310  
 00001320  
 00001330  
 00001340  
 00001350  
 00001360  
 00001370  
 00001380  
 00001390  
 00001400  
 00001410  
 00001420  
 00001430

```

EXX2T=EXX3(M)
ETT2T=ETT3(M)
ETX2T=ETX3(M)
EXX2T=EXX3(M)
ET2T=ET3(M)
DBX=-FDIFF(BX2T,BX2(M),BX1(M))
DBT=-FDIFF(BT2T,BT2(M),BT1(M))
DBXT=-FDIFF(BXT2T,BXT2(M),BXT1(M))
DBE=-FDIFF(BE2T,BE2(M),BE1(M))
DET=-FDIFF(ET2T,ET2(M),ET1(M))
DEX=-FDIFF(EX2T,EX2(M),EX1(M))
DEXX=-FDIFF(EXX2T,EXX2(M),EXX1(M))
DET2X=-FDIFF(ETX2T,ETX2(M),ETX1(M))
GO TO 7
8
DBX=TDLI*(BX3(M)-BX1(M))
DBT=TDLI*(BT3(M)-BT1(M))
DBE=TDLI*(BE3(M)-BE1(M))
DET=TDLI*(ET3(M)-ET1(M))
DEX=TDLI*(EX3(M)-EX1(M))
DEXX=TDLI*(EXX3(M)-EXX1(M))
DET2X=TDLI*(ETX3(M)-ETX1(M))
BX2T=BX2(M)
BT2T=BT2(M)
BE2T=BE2(M)
EXX2T=EXX2(M)
ET2T=ET2(M)
EX2T=EX2(M)
ET2T=ET2(M)
GEE(1)=GEE(1)+ENR*D1*OSE*(BS*(DBX+DBE+GA*D1*(BX2T-BT2T)+NU*(DBT+DBE)
      +ENR*D1*BX2T)+DBS*(BX2T+BE2T+NU*(BT2T+BE2T))-2.*OX*
      (EXX2T+ETX2T)-ENR*(EX2T+ET2T))*TDEL
1
2
GEE(2)=GEE(2)+OSE*(BS*(BS*(BX2T+BE2T+NU*(BT2T+BE2T))-D1*
      (DBXT+2.*GA*BX2T))*TDEL
1
2
GEE(3)=GEE(3)+OSE*(BS*(OX+NU*OT)*(BX2T+BE2T)+(OT+NU*OX))*
      (BT2T+BE2T))+2.*(GA*(EXX2T+ETX2T)+DEXX+DET2X+ENR*
      (EX2T+ET2T))*TDEL
1
2
50 IF(K*GT.1) GO TO 10
IF(M*GT.1) ELIS(1)=0.0
DO 20 I=1,4
GEES(I,M)=GEE(I)
SUMX=0.
DO 21 J=1,4

```





```

C*****
C FOLLOWING CARD CAUSES A SPECIFIED BOUNDARY CONDITION VALUE TO
C EXIST ONLY FOR MODE '0'.
C*****
C IF (M.NE.1) ELIS(J)=0
21 SUMX=SUMX+DL(I,J,M)*ELIS(J)+DG(I,J,M)*GEE(J)+DF(I,J,M)*FFS(J,M)
20 X(I,IK)=SUMX
10 DO 11 I=1,4
    DO 12 J=1,4
        SUMX=0.
12 SUMX=SUMX+DEE(I,J,IK)*GEE(J)-DST(I,J,IK)*X(J,IK1)
11 X(I,IK)=SUMX
4 CONTINUE
RETURN
END
C*****
00001440
*00001450
*00001460
*00001470
00001480
00001490
00001500
00001510
00001520
00001530
00001540
00001550
00001560
00001570
00001580
00001590

```

```

C*****
C SUBROUTINE MATINV(A,N,B,M,DETERM,IPIVOT,INDEX,NMAX,ISCALE)
C*****
C THIS SUBROUTINE SOLVES THE MATRIX EQUATION AX=B, WHERE A IS
C A SQUARE COEFFICIENT MATRIX AND B IS A MATRIX OF CONSTANT VEC-
C TORS.
C A(INVERSE) IS ALSO OBTAINED AND THE DETERMINANT OF A IS AVAIL-
C ABLE.
C THE FOLLOWING MUST BE DIMENSIONED IN THE CALLING PROGRAM:
C IPIVOT(N MAX), INDEX(N MAX,2), A(N MAX,N MAX), B(N MAX,N MAX)
C WHERE:
C A = NAME OF 2-DIMENSIONAL ARRAY TO BE INVERTED
C N = ORDER OF A - 1<=N<=NMAX
C B = NAME OF 2-DIMENSIONAL ARRAY TO BE MULTIPLIED
C BY A(INVERSE)
C M = NUMBER OF COLUMN VECTORS IN B
C NOTE: M = 0 SIGNALS INVERSION ONLY)
C IPIVOT = TEMPORARY STORAGE BLOCK
C INDEX = TEMPORARY STORAGE BLOCK
C NMAX = MAXIMUM ORDER OF A (AS DIMENSIONED IN THE
C CALLING PROGRAM)
C*****
00000010
00000020
*0000030
*0000040
*0000050
*0000060
*0000070
*0000080
*0000090
*0000100
*0000110
*0000120
*0000130
*0000140
*0000150
*0000160
*0000170
*0000180
*0000190
*0000200

```







```

250 B(ICOLU,M,L)=SWAP
260 INDEX(I,1)=IROW
270 INDEX(I,2)=ICOLU
310 PIVOT=A(ICOLU,ICOLU)
C
C SCALE THE DETERMINANT
C
1000 PIVOTI=PIVOT
1005 IF(ABS(DETERM)-R1)1030,1010,1010
1010 DETERM=DETERM/R1
ISCALE=ISCALE+1
1020 IF(ABS(DETERM)-R1)1060,1020,1020
DETERM=DETERM/R1
ISCALE=ISCALE+1
GO TO 1060
1030 IF(ABS(DETERM)-R2)1040,1040,1060
1040 DETERM=DETERM*R1
ISCALE=ISCALE-1
1050 IF(ABS(DETERM)-R2)1050,1050,1060
DETERM=DETERM*R1
ISCALE=ISCALE-1
1060 IF(ABS(PIVOTI)-R1)1090,1070,1070
1070 PIVOTI=PIVOTI/R1
ISCALE=ISCALE+1
1080 IF(ABS(PIVOTI)-R1)320,1080,1080
PIVOTI=PIVOTI/R1
ISCALE=ISCALE+1
GO TO 320
1090 IF(ABS(PIVOTI)-R2)2000,2000,320
2000 PIVOTI=PIVOTI*R1
ISCALE=ISCALE-1
2010 IF(ABS(PIVOTI)-R2)2010,2010,320
PIVOTI=PIVOTI*R1
ISCALE=ISCALE-1
320 DETERM=DETERM*PIVOTI
C
C DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
330 A(ICOLU,ICOLU)=1.0
340 DO 350 L=1,N
350 A(ICOLU,L)=A(ICOLU,L)/PIVOT
355 IF(M) 380, 380, 360
360 DO 370 L=1,M
370 B(ICOLU,L)=B(ICOLU,L)/PIVOT
C
C REDUCE NON-PIVOT ROWS
C
380 DO 550 L1=1,N

```

```

00000690
00000700
00000710
00000720
00000730
00000740
00000750
00000760
00000770
00000780
00000790
00000800
00000810
00000820
00000830
00000840
00000850
00000860
00000870
00000880
00000890
00000900
00000910
00000920
00000930
00000940
00000950
00000960
00000970
00000980
00000990
00001000
00001010
00001020
00001030
00001040
00001050
00001060
00001070
00001080
00001090
00001100
00001110
00001120
00001130
00001140
00001150
00001160

```



```

390 IF(L1-ICOLUM) 400, 550, 400
400 T=A(L1,ICOLUM)
420 A(L1,ICOLUM)=0.0
430 DO 450 L=1,N
450 A(L1,L)=A(L1,L)-A(ICOLUM,L)*T
455 IF(M) 550, 550, 460
460 DO 500 L=1,M
500 B(L1,L)=B(L1,L)-B(ICOLUM,L)*T
550 CONTINUE
C
C
C      INTERCHANGE COLUMNS
600 DO 710 I=1,N
610 L=N+1-I
620 IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630
630 JROW=INDEX(L,1)
640 JCOLUM=INDEX(L,2)
650 DO 705 K=1,N
660 SWAP=A(K,JROW)
670 A(K,JROW)=A(K,JCOLUM)
700 A(K,JCOLUM)=SWAP
705 CONTINUE
710 CONTINUE
740 RETURN
      END
00001170
00001180
00001190
00001200
00001210
00001220
00001230
00001240
00001250
00001260
00001270
00001280
00001290
00001300
00001310
00001320
00001330
00001340
00001350
00001360
00001370
00001380
00001390
00001400
00001410

```

```

SUBROUTINE ABC
C *****
C      THIS SUBROUTINE COMPUTES THE ELEMENTS OF THE A, BEE, AND C
C      MATRICES.
C *****
COMMON /BL1/ A(4,4),BEE(4,4),C(4,4)
COMMON /BL2/ TDLI,TDEL
COMMON /BL3/ DEL
COMMON /BL4/ E(4,4),F(4,4),G(4,4)
C *****
D2=2./DEL
00000010
00000020
00000030
00000040
00000050
00000060
00000070
00000080
00000090
00000100
00000110

```





```

DO 1 I=1,4
DO 1 J=1,4
DEIJ=D2*E(I,J)
FIJ=F(I,J)
BEE(I,J)=-2.*DEIJ+TDEL*G(I,J)
C(I,J)=DEIJ-FIJ
1 A(I,J)=DEIJ+FIJ
RETURN
END
00000120
00000130
00000140
00000150
00000160
00000170
00000180
00000190
00000200

```

```

SUBROUTINE PANDD(K,MN)
*****
THIS SUBROUTINE COMPUTES THE ELEMENTS OF THE P, P-BAR, AND
P-HAT MATRICES FOR EACH MEDIAN STATION K AND FOURIER MODE MN
THESE MATRICES ARE COMPUTED AND SAVED BECAUSE THEY DO NOT
CHANGE DURING EITHER THE ITERATION PROCEDURE OR THE LOAD INCRE-
MENT PROCEDURE - AS THEY ARE A FUNCTION OF THE SHELL'S INITIAL
GEOMETRY AND STIFFNESS.
*****
COMMON /IBL4/ KMAX,KL
COMMON /BL1/ A(4,4),BEE(4,4),C(4,4)
COMMON /BL4/ P(4,4,200),X(4,200),ZF1M(4,4,10),ZF2M(4,4,10),
1 ZF3M(4,4,10),ZF4M(4,4,10)
COMMON /BL34/ DEE(4,4,200),DST(4,4,200)
DIMENSION TM(4,4),IPIVOT(4),INDEX(4,2),X2(4)
*****
IKL=K+KMAX*(MN-1)
KL=IKL-1
DO 1 I=1,4
DO 1 J=1,4
SUM=0.
DO 2 L=1,4
SUM=SUM+C(I,L)*P(L,J,KL1)
1 TM(I,J)=BEE(I,J)-SUM
2 CALL MATINV(TM,4,X2,0,DETERM,IPIVOT,INDEX,4,ISCALE)
DO 5 I=1,4
DO 5 J=1,4
00000210
00000220
00000230
00000240
00000250
00000260
00000270
00000280
00000290
00000300
00000310
00000320
00000330
00000340
00000350
00000360
00000370
00000380
00000390
00000400
00000410
00000420
00000430
00000440
00000450
00000460
00000470

```



```

SUMA=0.
SUMC=0.
DO 6 L=1,4
SUMA=SUMA+TM(I,L)*A(L,J)
SUMC=SUMC+TM(I,L)*C(L,J)
P(I,J,IKL)=SUMA
DEE(I,J,IKL)=TM(I,J)
DST(I,J,IKL)=SUMC
5 RETURN
END

```

170



```

C      THE LOCATION OF THE INDEX AND THE VARIABLE MAXSY STORES THE
C      TOTAL NUMBER OF SUCH COMBINATIONS.
C      WITH THIS PROCEDURE, THE SERIES OF PRODUCTS THAT MAKE UP THE
C      BETA'S AND AETA'S CONTAIN NO ZERO TERM, AND THE SUMMATION IS
C      CARRIED OUT IN PHIBET(K) AND TEAETA(K) OVER SPECIFICALLY DE-
C      FINED LIMITS.
C      *****
C      COMMON /IBL1/ MNMAX
C      COMMON /IBL2/ N(10), MNINIT
C      COMMON /IBL7/ MNMAXO, MAXD(10), MAXS(10), MAXSY(10), IS(10,10),
1      JS(10,10), ID(10,10), JD(10,10), IJS(10)
C      *****
C      COMMON /IBL9/ MAXM
C      COMMON /IBL11/ ICORFL, IPASS
C      *****
C      IF(MAXM.EQ.1) RETURN
C      IF(MNINIT.GT.MAXM) RETURN
C      DO 1 MN=1, MNMAXO
C      MN=N(MN)
C      NNS=MN
C      IF(MNINIT.GT.MN) NNS=MNINIT
C      DO 1 MM=NNS, MNMAXO
C      NMM=N(MM)
C      NTEST=IABS(NMN-MM)
C      DO 2 MMFT=1, MNMAX
C      IF(NTEST.EQ.N(MMFT)) GO TO 10
2      CONTINUE
C      IF(ICORFL.EQ.1) GO TO 1
C      MNMAX=MNMAX+1
C      N(MNMAX)=NTEST
C      MMFT=MNMAX
C      IF(MNMAX.EQ.MAXM) ICORFL=1
10      IF(NMN-MM) 11,1,12
11      LOCD=MAXD(MMFT)+1
C      MAXD(MMFT)=LOCD
C      ID(LOCD,MMFT)=MM
C      JD(LOCD,MMFT)=MN
C      GO TO 1
12      LOCD=MAXD(MMFT)+1
C      MAXD(MMFT)=LOCD
C      ID(LOCD,MMFT)=MN
C      JD(LOCD,MMFT)=MM
1      CONTINUE
C      DO 301 MN=1, MNMAXO
C      NMN=N(MN)
C      NNS=MN
C      IF(MNINIT.GT.MN) NNS=MNINIT
C      DO 301 MM=NNS, MNMAXO
C      NMM=N(MM)

```



```

NTEST=NMN+MMM
DO 302 MMFT=1, MNMAX
IF(NTEST.EQ.N(MMFT)) GO TO 310
CONTINUE
IF(ICORFL.EQ.1) GO TO 301
IF(MNMAX.GE.MAXM) GO TO 301
MNMAX=MNMAX+1
N(MNMAX)=NTEST
MMFT=MNMAX
IF(MNMAX.GE.MAXM) ICORFL=1
IF(NMN.EQ.NMM) GO TO 360
LOCS=MAXS(MMFT)+1
MAXS(MMFT)=LOCS
IS(LOCS,MMFT)=MN
JS(LOCS,MMFT)=MM
GO TO 301
360 IF(NMN.EQ.0) GO TO 301
MAXSY(MMFT)=1
IJS(MMFT)=MN
CONTINUE
301 MNINIT=MNMAXO+1
IF(ICORFL.GT.0) IPASS=IPASS+1
IF(IPASS.LT.2.AND.MNINIT.LE.MNMAX) CALL PMATRIX
RETURN
END

```

```

00000750
00000760
00000770
00000780
00000790
00000800
00000810
00000820
00000830
00000840
00000850
00000860
00000870
00000880
00000890
00000900
00000910
00000920
00000930
00000940
00000950
00000960
00000970
00000980
00000990

```

```

SUBROUTINE HJ(K,MN)
C*****
C THIS SUBROUTINE COMPUTES THE ELEMENTS OF THE H AND JAY
C MATRICES FOR BOTH BOUNDARIES OF THE SHELL
C*****
REAL L2,LAM2,LSDIN, LSD18,JAY,NU
COMMON /IBL2/ N(10),MNINIT
COMMON /IBL4/ KMAX,KL
COMMON /BL8/ R(200),GAM(200),OMT(200)
COMMON /BL11/ OMXI(200),PHEE,T0,T2
COMMON /BL14/ LAM2,LSD18,LSDIN

```

```

00000010
00000020
00000030
00000040
00000050
00000060
00000070
00000080
00000090
00000100
00000110

```





```

COMMON /BL15/ NU,U1(10),V1(10),W1(10),V2(10),U2(10),W2(10),U3(10),
1      V3(10),W3(10),00000120,00000130,00000140,00000150,00000160,00000170,00000180,00000190,00000200,00000210,00000220,00000230,00000240,00000250,00000260,00000270,00000280,00000290,00000300,00000310,00000320,00000330,00000340,00000350,00000360,00000370,00000380,00000390,00000400,00000410,00000420,00000430,00000440,00000450,00000460,00000470,00000480,00000490,00000500,00000510,00000520,00000530,00000540,00000550,00000560,00000570,00000580,00000590
COMMON /BL17/ DEL
COMMON /BL20/ DEOMX(200)
COMMON /BL23/ JAY(4,4),H(4,4)
EQUIVALENCE(L2,LAM2)
*****
CALL BDB(K,B,DB,D,DD)
YAH=1.
IF(K.EQ.1.OR.K.EQ.KMAX)YAH=2.
DI=(1.-NU)
GA=GAM(K)
OX=OMXI(K)
RA=R(K)
EN=N(MN)
ENR=EN/RA
REG=0.
IF(YAH.EQ.2.) REG=1.
OT=OMT(K)
OXT=3.*OMXI(K)-OMT(K)
OTX=3.*OMT(K)-OMXI(K)
DL=D*L2*D1*ENR
H(1,1)=B
H(1,2)=0.
H(1,3)=0.
H(1,4)=0.
H(2,1)=0.
H(2,2)=B*D1/2.+L2*D*D1/8.*OTX**2*REG
H(2,3)=DL/2.*OTX*REG
H(2,4)=0.
H(3,1)=0.
H(3,2)=DL*OTX*YAH/4.
ENR2=ENR**2
H(3,3)=L2*D*D1*(YAH*ENR2+(1.+NU)*GA**2)
GA2=GA**2
H(3,4)=L2
H(4,1)=0.
H(4,2)=0.
H(4,3)=-1.
H(4,4)=0.
JAY(1,1)=NU*GA*B
JAY(1,2)=NU*B*ENR
JAY(1,3)=B*(OX+NU*OT)
JAY(1,4)=0.
JAY(2,1)=-B*D1*ENR/2.-DL/8.*OXT*OTX*REG
JAY(2,2)=-GA*H(2,2)
JAY(2,3)=-GA*H(2,3)
JAY(2,4)=0.

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```

00000600
00000610
00000620
00000630
00000640
00000650
00000660
00000670
00000680
00000690
00000700
00000710
00000720

```

```

JAY(3,1)=-L2*D#D1*((1.+NU)*GA2*OX+ENR2/4.*OXT*YAH)
JAY(3,2)=-GA*DL/2.*{ 2.*OT*(1.+NU)+OTX/2.*YAH)
JAY(3,3)=-L2*D#D1*((1.+NU+YAH)*GA*ENR2
JAY(3,4)=L2*D#D1*GA
JAY(4,1)=OX
JAY(4,2)=0.
JAY(4,3)=0.
JAY(4,4)=0.
DO 1 I=1,4
DO 1 J=1,4
1 H(I,J)=H(I,J)/2./DEL
RETURN
END

```

```

SUBROUTINE POLE(K)
C *****
C THIS SUBROUTINE PRINTS THE SOLUTION AT AN INITIAL AND A FINAL
C POLE.
C *****
IMPLICIT LOGICAL#1 ($)
REAL NU,MT,MX,MTH,MXT,MTS,KX,KT,KXT,LAM,LAM2,MASS
COMMON /IBL2/ N(10),MNINIT
COMMON /IBL3/ MO,M1,M2,M3
COMMON /IBL4/ KMAX,KL
COMMON /IBL5/ IBCINL,IBCFNL
COMMON /IBL7/ MNMAXO,MAXD(10),MAXS(10),MAXSY(10),IS(10,10),
1 JS(10,10),ID(10,10),JD(10,10),IJS(10,
COMMON /IBL8/ LSTEP,ITR
COMMON /IBL10/ IFREQ,NTHMAX
COMMON /IBL12/ KMAX1,KMAX2,NCONV
COMMON /BL4/ P(4,4,200),X(4,200),ZF1M(4,4,10),ZF2M(4,4,10),
1 ZF3M(4,4,10),ZF4M(4,4,10)
COMMON /BL5/ TT(10),MT(13),DT(10),DMT(10)
COMMON /BL6/ Z(4,220),SOE,OSE,ALOAD
COMMON /BL7/ D1,S1
COMMON /BL8/ R(200),GAM(200),OMT(200)
COMMON /BL10/ PHIX(10),PHIT(10),PHI(10)
COMMON /BL10/
00000010
00000020
00000030
00000040
00000050
00000060
00000070
00000080
00000090
00000100
00000110
00000120
00000130
00000140
00000150
00000160
00000170
00000180
00000190
00000200
00000210
00000220
00000230

```



```

COMMON /BL11/ QMXI(200),PHEE,T0,T2 00000240
COMMON /BL12/ TDL1,TDEL 00000250
COMMON /BL14/ LAM2,LSD18,LSD1N 00000260
COMMON /BL15/ NU,U1(10),V1(10),W1(10),V2(10),U2(10),W2(10),U3(10), 00000270
1 V3(10),W3(10) 00000280
COMMON /BL17/ DEL 00000290
COMMON /BL19/ TH(36) 00000300
COMMON /BL20/ DEOMX(200) 00000310
COMMON /BL27/ BX3(10),BT3(10),BXT3(10),BE3(10) 00000320
COMMON /BL31/ DELSQ,EXT1(10) 00000330
COMMON /BL32/ TKN,ELAST,CHAR,SIGO 00000340
COMMON /BL100/ TEE0,$DYNMC 00000350
COMMON /BL101/ ZO(4,220),Z2(4,220),Z3(4,220),DELSO 00000360
COMMON /BL102/ DELOAD 00000370
COMMON /BL103/ MASS(200) 00000380
COMMON /BL110/ TX(10),TTH(10),TXT(10),MX(10),MTH(10),MXT(10), 00000390
1 OS(10) 00000400
COMMON /BL111/ ABZ,ABZO,ABZN,ABZ3,DD2 00000410
C ***** 00000420
CALL BDB(K,BS,DB,DS,DD) 00000430
IF(K.EQ.KMAX) GO TO 301 00000440
DO 202 MN=1,MNMAX 00000450
U1(MN)=U2(MN) 00000460
V1(MN)=V2(MN) 00000470
W1(MN)=W2(MN) 00000480
I3=3+(MN-1)*KMAX2 00000490
I2=I3-1 00000500
U2(MN)=Z(1,I3) 00000510
V2(MN)=Z(2,I3) 00000520
W2(MN)=Z(3,I3) 00000530
PHIX(MN)=0.0 00000540
PHIT(MN)=0.0 00000550
PHI(MN)=0.0 00000560
MX(MN)=Z(4,I2)*ABZ3 00000570
MTH(MN)=0.0 00000580
MXT(MN)=0.0 00000590
QS(MN)=0.0 00000600
TX(MN)=0.0 00000610
TTH(MN)=0.0 00000620
TXT(MN)=0.0 00000630
IF(M1.EQ.0) GO TO 203 00000640
CALL INLPOL 00000650
PHIX(M1)=PHEE*ABZO 00000660
PHIT(M1)=-PHEE*ABZO 00000670
QS(M1)=0.0 00000680
NOTE: CARDS SERIALIZED #00000690 THRU #00000800 HAVE BEEN REMOVED. 00000680
IF(M0.EQ.0) GO TO 204 00000680
TX(M0)=TO*ABZ 00000820

```



```

TTH(M0) =T0*ABZ
MTH(M0) =MX(M0)
234 IF(M2.EQ.0) GO TO 205
TX(M2) = T2*ABZ
TTH(M2) =-T2*ABZ
TX(M2) =-T2*ABZ
MTH(M2) =-MX(M2)
MXT(M2) =MTH(M2)
GO TO 205
203 IF(M0.EQ.0) GO TO 206
I3=3+(M0-1)*KMAX2
I4=I3+1
CALL TLOAD(1)
TX(M0) =BS*SI*((2.*Z(1,I3)-.5*Z(1,I4))/DEL+OMXI(1)*Z(3,I3-1))*ABZ
1 -TT(M0)*ABZ*ALOAD
TTH(M0) =TX(M0)
MTH(M0) =MX(M0)
206 IF(M2.EQ.0) GO TO 205
I3=3+(M2-1)*KMAX2
I4=I3+1
TX(M2) =BS*DI*((2.*Z(1,I3)-.5*Z(1,I4))/DEL
TTH(M2) =TX(M2)*ABZ
TX(M2) =-TX(M2)
TX(M2) =-TX(M2)
MTH(M2) =-MX(M2)
MXT(M2) =-MX(M2)
205 RETURN
301 CONTINUE
DO 302 MN=1,MNMAX0
U1(MN) =U2(MN)
V1(MN) =V2(MN)
W1(MN) =W2(MN)
PHIX(MN) =0.
PHIT(MN) =0.
PHI(MN) =0.
IK=KMAX1+(MN-1)*KMAX2
MX(MN) =Z(4,IK)*ABZ3
MTH(MN) =0.
MXT(MN) =0.
QS(MN) =0.
TX(MN) =0.
TTH(MN) =0.
302 TX(MN) =0.
IF(M1.EQ.0) GO TO 303
CALL FNLPOL
PHIX(M1) =PHEE*ABZ0
PHIT(M1) = PHEE*ABZ0
QS(M1) =0.

```





```

C      NOTE: CARDS SERIALIZED #00001310 THRU #00001430 HAVE BEEN REMOVED.
      IF(MO.EQ.0) GO TO 304
      TX(MO) = TO*ABZ
      TTH(MO) = TO*ABZ
      MTH(MO) = MX(MO)
304   IF(M2.EQ.0) GO TO 305
      TX(M2) = T2*ABZ
      TTX(M2) = -T2*ABZ
      MTH(M2) = -MX(M2)
      MXT(M2) = MX(M2)
      GO TO 305
303   IF(MO.EQ.0) GO TO 306
      IKM=KMAX+(MO-1)*KMAX2
      IM1=IKM-1
      CALL TLOAD(KMAX)
      TX(MO)=BS*S1*((-2.*Z(1,IKM)+.5*Z(1,IM1))/DEL+OMX I(KMAX)*Z(3,IKM+1))
1     TX(MO)=BS*ABZ-TT(MO)*ABZ*ALOAD
      TTH(MO) = TX(MO)
      MTH(MO) = MX(MO)
306   IF(M2.EQ.0) GO TO 305
      IKM=KMAX+(M2-1)*KMAX2
      IM1=IKM-1
      TX(M2)=BS*D1*((-2.*Z(1,IKM)+.5*Z(1,IM1))/DEL
      TX(M2)=TX(M2)*ABZ
      TTH(M2) = -TX(M2)
      TTX(M2) = TX(M2)
      MTH(M2) = -MX(M2)
      MXT(M2) = MX(M2)
305   RETURN
      END

```

```

C      SUBROUTINE PLOTIT(X,Y,NN,MODCUR)
C      *****
C      THIS SUBROUTINE AND THE THREE THAT FOLLOW IT COMPRISE THE SELF-
C      CONTAINED PLOTTING CAPABILITY OF THE PROGRAM, SATANS. THEY RECEIVE
C      THE DATA TO BE PLOTTED, ROUND IT, SCALE IT AND DRAW IT ON THE HIGH-

```























```

C***** GO TO 444 0001920
C***** 00001930
C***** 00001940
C***** 00001950
C***** 00001960
C***** 00001970
C***** 00001980
C***** 00001990
C***** 00002000
C***** 00002010
C***** 00002020
C***** 00002030
C***** 00002040
C***** 00002050
C***** 00002060
C***** 00002070
C***** 00002080
C***** 00002090
C***** 00002100
C***** 00002110
C***** 00002120
C***** 00002130
C***** 00002140
C***** 00002150
C***** 00002160
C***** 00002170
C***** 00002180
C***** 00002190
C***** 00002200
C***** 00002210
C***** 00002220
C***** 00002230
C***** 00002240
C***** 00002250
C***** 00002260
C***** 00002270
C***** 00002280
C***** 00002290
C***** 00002300
C***** 00002310
C***** 00002320
C***** 00002330
C***** 00002340
C***** 00002350
C***** 00002360
C***** 00002370
C***** 00002380
C***** 00002390

IF(MODCUR.GT.1) GO TO 444
GRID IS THE MATRIX USED TO PLOT THE POINTS
IERR=0
XMAX=RANGE(1)
XMIN=RANGE(2)
YMAX=RANGE(3)
YMIN=RANGE(4)
CHECKING X AND Y POINTS AND PLOTTING THOSE OUT OF RANGE
AT THE MARGIN
DO 30 I=1,KDATA,KKZ
IF(X(I).GT.XMAX.OR.X(I).LT.XMIN.OR.Y(I).GT.YMAX.OR.Y(I).LT.YMIN)
1 IERR=IERR+1
IF(X(I).LE.XMAX) GO TO 205
X(I)=XMAX
GO TO 210
205 IF(X(I).GE.XMIN) GO TO 210
X(I)=XMIN
210 IF(Y(I).LE.YMAX) GO TO 215
Y(I)=YMAX
GO TO 30
215 IF(Y(I).GE.YMIN) GO TO 30
Y(I)=YMIN
30 CONTINUE
PLOTTING X AND Y AXIS , IF NECESSARY
JERR=0
XRANGE=XMAX-XMIN
YRANGE=YMAX-YMIN
IF (YRANGE.NE.0.) GO TO 298
IF(YMIN.EQ.0.) GO TO 889
YMIN=0.
YRANGE=YMAX
GO TO 299
298 IF (XRANGE.NE.0.) GO TO 299
IF(XMIN.EQ.0.) GO TO 887
XMIN=0.
XRANGE=XMAX
BLANKING OUT MATRIX-(GRID)
299 DO 300 I=1,61
DO 301 JJ=1,81
301 GRID(I,JJ)=BLANK

```









```

C*****
17 IF(MODCUR.EQ.1.OR.MODCUR.EQ.2) RETURN
   AXR=ABS(XRANGE)
   AYR=ABS(YRANGE)
   IF(AXR.LT.1.E+8.AND.AXR.GE..95) GO TO 400
   WRITE(6,17) XSCALE
   FORMAT(12X,1PE10.3,4(10X,E10.3)/15X,'**',8('++++*****'),'+**')
   GO TO 401
400 WRITE(6,117) XSCALE
117 FORMAT( 8X,F11.2,4( 9X,F11.2)/15X,'**',8('++++*****'),'+**')
401 II=1
   DO 101 IK=1,61
   IF(MOD(IK-1,10).NE.0) GO TO 92
   IF(AYR.LT.1.E+8.AND.AYR.GE..95) GO TO 404
   WRITE(6,18) YSCALE(II),(GRID(IK,IX),IX=1,81),YSCALE(II)
   FORMAT(3X,1PE10.3,2X,1H+,1X,81A1,1X,1H+,2X,E10.3)
18 GO TO 405
404 WRITE(6,118) YSCALE(II),(GRID(IK,IX),IX=1,81),YSCALE(II)
118 FORMAT(2X,F11.2,' + ',81A1,' + ',F11.2)
405 II=II+1
   GO TO 101
92 WRITE(6,19) (GRID(IK,IX),IX=1,81)
19 FORMAT(15X,'* ',81A1,'*')
101 CONTINUE
   IF(AXR.LT.1.E+8.AND.AXR.GE..95) GO TO 402
   WRITE(6,22) XSCALE
   FORMAT(15X,'**',8('++++*****'),'+**'/12X,1PE10.3,4(10X,E10.3),//)
22 GO TO 403
402 WRITE(6,217) XSCALE
217 FORMAT(15X,'**',8('++++*****'),'+**'/ 8X,F11.2,4( 9X,F11.2),//)
403 IF(IERR.GT.0) WRITE(6,20) IERR
20 FORMAT(10X,'NUMBER OF POINTS OUT OF RANGE =' I4)
1000 RETURN
889 WRITE(6,888)
888 FORMAT(' ALL Y VALUES=0. CANNOT SETUP PLOT GRID. CHECK MAX & MIN Y')
1 WHEN MODCUR=0 OR 1.)
   JERR=10
   RETURN
887 WRITE(6,886)
886 FORMAT(' ALL X VALUES=0. CANNOT SETUP PLOT GRID. CHECK MAX & MIN X')
1 WHEN MODCUR=0 OR 1.)
   JERR=10
   RETURN
885 WRITE(6,884)
884 FORMAT(' GRID NOT SETUP WHEN MODCUR LAST 0 OR 1. NO PLOT UNTIL GRID PROPERLY SETUP,')
1D RETURN
END
*****00002880
*****00002890
*****00002900
*****00002910
*****00002920
*****00002930
*****00002940
*****00002950
*****00002960
*****00002970
*****00002980
*****00002990
*****00003000
*****00003010
*****00003020
*****00003030
*****00003040
*****00003050
*****00003060
*****00003070
*****00003080
*****00003090
*****00003100
*****00003110
*****00003120
*****00003130
*****00003140
*****00003150
*****00003160
*****00003170
*****00003180
*****00003190
*****00003200
*****00003210
*****00003220
*****00003230
*****00003240
*****00003250
*****00003260
*****00003270
*****00003280
*****00003290
*****00003300
*****00003310
*****00003320
*****00003330
*****00003340
*****00003350

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SUBROUTINE XANDZ
C*****
C THIS SUBROUTINE COMPUTES THE X VECTOR USING THE P, PBAR, AND
C P-HAT MATRICES AND SOLVES FOR THE Z VECTOR FOR THE APPLIED AND
C PSUEDO LOADS. THE SUBROUTINES PHIBET(K) AND TEAETA(K) ARE
C CALLED AND THE PREVIOUS SOLUTION FOR Z, OR THE ESTIMATED VALUE
C OF Z IS USED TO CALCULATE THE NON-LINEAR OF BETA AND AETA TERMS.
C THE MATRICES USED TO CALCULATE THE VALUES OF SMALL-F AT THE
C INITIAL AND FINAL EDGES OF THE SHELL. THE SUBROUTINE FORCE(K)
C IS CALLED AND TO CALCULATE THE LOAD VECTOR GEE, AND THE X VECTOR
C EACH MERIDIAN STATION. ONCE THE X VECTOR IS OBTAINED FOR ALL
C MERIDIAN STATIONS AND THE SOLUTION FOR Z(K+1) GIVEN BY EQUATION
C (31B) OF REF. 3 IS OBTAINED, AND THE SOLUTION FOR Z(I) AT ALL
C OTHER MERIDIAN STATIONS DEFINED BY EQUATION (29B) OF REF. 3 IS
C OBTAINED. THE SOLUTION Z AT THE IMAGINARY STATION OFF THE
C INITIAL EDGE OF THE SHELL IS OBTAINED LAST. THE TEST FOR CON-
C VERGENCE OF THE SOLUTION IS MADE AS Z IS COMPUTED. THE SPE-
C CIAL CONDITIONS FOR COMPUTING Z AT EITHER AN INITIAL POLE OR
C FINAL POLE ARE ALSO IN THIS ROUTINE.
C*****
C IMPLICIT LOGICAL*1 ($)
C REAL NU, LAM2, MT, MNMAX
C COMMON /IBL1/ MNMAX
C COMMON /IBL3/ MO, M1, M2, M3
C COMMON /IBL4/ KMAX, KL
C COMMON /IBL5/ IBCINL, IBCFNL
C COMMON /IBL6/ KLL
C COMMON /IBL7/ MNMAXO, MAXD(10), MAXS(10), MAXSY(10), IS(10,10),
C 1 JS(10,10), ID(10,10), JD(10,10), IJS(10,
C /IBL8/ LSTEP, ITR
C COMMON /IBL12/ KMAX1, KMAX2, NCONV
C COMMON /IBL13/ ITRMAX, LSMAX
C COMMON /BL1/ A(4,4), BEE(4,4), C(4,4)
C COMMON /BL3/ PR(10), PX(10), PT(10)
C COMMON /BL4/ P(4,4,200), X(4,200), ZF1M(4,4,10), ZF2M(4,4,10),
C 1 ZF3M(4,4,10), ZF4M(4,4,10)
C*****
00000010
00000020
00000030
00000040
00000050
00000060
00000070
00000080
00000090
00000100
00000110
00000120
00000130
00000140
00000150
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00000170
00000180
00000190
00000200
00000210
00000220
00000230
00000240
00000250
00000260
00000270
00000280
00000290
00000300
00000310
00000320
00000330
00000340
00000350
00000360

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COMMON /BL5/      TT(10),MT(10),DT(10),DMT(10)
COMMON /BL6/      Z(4,220),SOE,OSE,ALOAD
COMMON /BL7/      D1,S1
COMMON /BL8/      R(200),GAM(200),OMT(200)
COMMON /BL9/      FFS(4,10),ELIS(4),GEES(4,10)
COMMON /BL14/     LAM2,LSD18,LSDIN
COMMON /BL15/     NU,U1(10),V1(10),W1(10),V2(10),U2(10),W2(10),U3(10),
1 V3(10),W3(10)
COMMON /BL16/     EPS
COMMON /BL18/     EL1(4),ELL(4)
COMMON /BL27/     BX3(10),BT3(10),BXT3(10),BE3(10)
COMMON /BL28/     EXX3(10),ETT3(10),ETX3(10),EXT3(10),ET3(10)
COMMON /BL29/     BX1(10),BT1(10),BXT1(10),BX2(10),BT2(10),
1 BXT2(10),BE2(10)
COMMON /BL30/     EXX1(10),ETT1(10),ETX1(10),EX1(10),ET1(10),EXX2(10),
1 ETT2(10),ETT2(10),EXT2(10),EX2(10),ET2(10)
COMMON /BL31/     DELSQ,EXT1(10)
COMMON /BL100/    TEEQ,$DYNMC
COMMON /BL101/    ZQ(4,220),Z2(4,220),Z3(4,220),DELSQ
COMMON /BL102/    DELOAD
COMMON /BL103/    MASS(200)
COMMON /BL104/    ZDOT(4,220)
DIMENSION ELLS(4),FLS(4),ZT(4),PIVOT(4),INDEX(4,2)
1,CLO(4,4),CL1(4,4),CL2(4,4)
2,TZMAX(4,10),ZDD(4)
EQUIVALENCE (CLO(1),ZF1M(1)),(CL1(1),ZF2M(1)),(CL2(1),ZF3M(1))
C*****
DO 201 I=1,4
DO 201 M=1,MNMAX
MJ=1+(M-1)*KMAX2
TZMAX(I,M)=ABS(Z(I,MJ))
DO 201 K=2,KMAX2
KM=K+(M-1)*KMAX2
AZTST=ABS(Z(I,KM))
IF(AZTST.GT.TZMAX(I,M)) TZMAX(I,M)=AZTST
201 CONTINUE
NCONV=1
IF(ITRMAX.EQ.1) GO TO 66
DO 1 M=1,MNMAX0
I=1+(KMAX+2)*(M-1)
U1(M)=Z(1,I)
V1(M)=Z(2,I)
W1(M)=Z(3,I)
I1=I+1
U2(M)=Z(1,I1)
V2(M)=Z(2,I1)
W2(M)=Z(3,I1)
1 IF(IBCINL.LT.0) GO TO 100
00000370
00000380
00000390
00000399
00000410
00000420
00000430
00000440
00000450
00000460
00000470
00000480
00000490
00000500
00000510
00000520
00000530
00000540
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00000610
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00000640
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00000670
00000680
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00000720
00000730
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00000750
00000760
00000770
00000780
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00000810
00000820
00000830
00000840

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CALL PHIBET(1)
DO 2 M=1,MNMAX
  BX1(M)=BX3(M)
  BT1(M)=BT3(M)
  BXT1(M)=BXT3(M)
  BE1(M)=BE3(M)
2  CALL TEAETA(1)
  DO 3 M=1,MNMAX
    EXX1(M)=EXX3(M)
    ETT1(M)=ETT3(M)
    ETX1(M)=ETX3(M)
    EX1(M)=EX3(M)
    ET1(M)=ET3(M)
3  CALL PHIBET(2)
  DO 4 M=1,MNMAX
    BX2(M)=BX3(M)
    BT2(M)=BT3(M)
    BXT2(M)=BXT3(M)
    BE2(M)=BE3(M)
4  CALL TEAETA(2)
  DO 5 M=1,MNMAX
    EXX2(M)=EXX3(M)
    ETT2(M)=ETT3(M)
    ETX2(M)=ETX3(M)
    EX2(M)=EX3(M)
    ET2(M)=ET3(M)
5  CALL PHIBET(3)
  CALL TEAETA(3)
66 CONTINUE
  IF(IBCINL.LT.0) GO TO 20
  CALL BDB(1,B1,DB,D,DD)
  GAM1=GAM(1)
  CALL TLOAD(1)
  DO 8 M=1,MNMAX
    IF(ITRMAX.EQ.1) GO TO 67
    FFS(1,M)=-TT(M)*ALOAD+OSE*(BX1(M)+BE1(M)+NU*(BT1(M)+BE1(M))*B1
    FFS(2,M)=OSE*(B1*DI*BT1(M)+EX1(M)+ET1(M))
    FFS(3,M)=LAM2*GAM1*DI*MT(M)*ALOAD-(EXX1(M)+ETX1(M))*SOE
    GO TO 8
67 FFS(1,M)=-TT(M)*ALOAD
    FFS(2,M)=0.
    FFS(3,M)=LAM2*GAM1*DI*MT(M)*ALOAD
    FFS(4,M)=0.
    DO 9 I=1,4
      ELIS(I)=ALOAD*EL1(I)
    CALL FORCE(1)

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00000850
00000860
00000870
00000880
00000890
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00000910
00000920
00000930
00000940
00000950
00000960
00000970
00000980
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00001000
00001010
00001020
00001030
00001040
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00001060
00001070
00001080
00001090
00001100
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00001120
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00001140
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00001180
00001190
00001200
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00001290
00001300
00001310
00001320

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```

20 CALL FORCE(2)
DO 10 K=3,KLL
KP=K+1
IF(ITRMAX.EQ.1) GO TO 10
CALL UPDATE
CALL PHIBET(KP)
CALL TEAETA(KP)
10 CALL FORCE(K)
IF(ITRMAX.NE.1) CALL UPDATE
IF(IBCFL.LT.0) GO TO 120
IF(ITRMAX.EQ.1) GO TO 11
CALL PHIBET(KMAX)
CALL TEAETA(KMAX)
11 CALL FORCE(KL)
CALL FORCE(KMAX)
DO 12 I=1,4
ELLS(I)=ALOAD*ELL(I)
12 CALL BDB(KMAX,BL,DB,D,DD)
GAML=GAM(KMAX)
FLS(4)=0.
CALL TLOAD(KMAX)
DO 14 M=1,MNMAX
IF(M.GT.1) ELLS(1)=0.0
IF(ITRMAX.EQ.1) GO TO 68
FLS(1)=-TT(M)*ALOAD+OSE*(BX3(M)+BE3(M)+NU*(BT3(M)+BE3(M))*BL
FLS(2)=-OSE*(BL*DI*BT3(M)+ET3(M))
FLS(3)=LAM2*GAML*DI*MT(M)*ALOAD-(EXX3(M)+ETX3(M))*SOE
GO TO 69
68 FLS(1)=-TT(M)*ALOAD
FLS(2)=0.
FLS(3)=LAM2*GAML*DI*MT(M)*ALOAD
69 CONTINUE
IK=KL+KMAX*(M-1)
IJ=KMAX*M
L=M*KMAX2
DO 14 I=1,4
SUMZ=0.
DO 15 J=1,4
C*****
C THE FOLLOWING CARD CAUSES BOUNDARY CONS TO EXIST FOR MODE 10, ONLY
C*****
15 SUMZ=SUMZ+ZF1M(I,J,M)*ELLS(J)+ZF2M(I,J,M)*X(J,I,J)+ZF3M(I,J,M)*
14 X(J,IK)+ZF4M(I,J,M)*FLS(J)
LS=1
150 DO 16 M=1,MNMAX
DO 16 L=LS,KMAX
00001330
00001340
00001350
00001360
00001370
00001380
00001390
00001400
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00001430
00001440
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00001480
00001490
00001500
00001510
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00001580
00001590
00001600
00001610
00001620
00001630
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00001770
00001780
00001790
00001800

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```

K=KMAX2-L
KPX=K-1
KZ=K+1
IJ=KPX+(M-1)*KMAX
JK=KZ+(M-1)*KMAX2
KK=JK-1
DO 17 I=1,4
SUMZ=0.
DO 18 J=1,4
SUMZ=SUMZ-P(I,J,IJ)*Z(J,JK)
SUMZ=SUMZ+X(I,IJ)
ASUMZ=ABS(SUMZ)
IF(ASUMZ.GT.1.E+15) ITR=ITRMAX
IF(NCONV.NE.1.OR.ASUMZ.LT.1.E-05) GO TO 17
DELZ=ABS(Z(I,KK)-SUMZ)
ZTEST=EPS*ITRMAX(I,M)
IF(DELZ.GT.ZTEST) NCONV=0
Z(I,KK)=SUMZ
17 CONTINUE
16 IF(BCINL.LT.0) GO TO 30
DO 25 M=1,MNMAX
CALL EFG(1,M)
CALL ABC
IJ=2+(M-1)*KMAX2
IJ1=IJ+1
IJ2=IJ-1
DO 21 I=1,4
SUMZ=0.
DO 22 J=1,4
SUMZ=SUMZ-A(I,J)*Z(J,IJ1)-BEE(I,J)*Z(J,IJ)
22 ZT(I)=SUMZ+GEES(I,M)
21 CALL MATINV(C,4,ZT,1,DETERM,IPIVOT,INDEX,4,ISCALE)
DO 23 I=1,4
Z(I,IJ2)=ZT(I)
23 CONTINUE
25 RETURN
100 CALL INLPOL
DO 101 M=1,MNMAX0
U1(M)=U2(M)
V1(M)=V2(M)
W1(M)=W2(M)
IJ=3+KMAX2*(M-1)
U2(M)=Z(1,IJ)
V2(M)=Z(2,IJ)
W2(M)=Z(3,IJ)
101 GO TO 102
120 IF(ITRMAX.NE.1) CALL FNLPOL
CALL FORCE(KL)

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00001810
00001820
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00001910
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00001960
00001970
00001980
00001990
00002000
00002010
00002020
00002030
00002040
00002050
00002060
00002070
00002080
00002090
00002100
00002110
00002120
00002130
00002140
00002150
00002160
00002170
00002180
00002190
00002200
00002210
00002220
00002230
00002240
00002250
00002260
00002270
00002280

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```

IF(M2.EQ.0) GO TO 122
L=KL+(M2-1)*KMAX
L1=KMAX1+(M2-1)*KMAX2
DO 130 I=1,4
SUM=0.
DO 131 J=1,4
SUM=SUM+CL2(I,J)*X(J,L)
131 ASUMZ=ABS(SUM)
IF(NCONV.NE.1.OR. ASUMZ.LT.1.E-05) GO TO 130
DELZ=ABS(Z(I,L1)-SUM)
ZTEST=EPS*TZMAX(I,M2)
IF(DELZ.GT.ZTEST) NCONV=0
Z(I,L1)=SUM
130 IF(M1.EQ.0) GO TO 123
122 L=KL+(M1-1)*KMAX
L1=KMAX1+(M1-1)*KMAX2
DO 132 I=1,4
SUM=0.
DO 133 J=1,4
SUM=SUM+CL1(I,J)*X(J,L)
133 ASUMZ=ABS(SUM)
IF(NCONV.NE.1.OR. ASUMZ .LT. 1.E-05) GO TO 132
DELZ=ABS(Z(I,L1)-SUM)
ZTEST=EPS*TZMAX(I,M1)
IF(DELZ.GT.ZTEST) NCONV=0
Z(I,L1)=SUM
132 IF(M0.EQ.0) GO TO 124
123 L=KL+(M0-1)*KMAX
L1=KMAX1+(M0-1)*KMAX2
DO 134 I=1,4
SUM=0.
DO 135 J=1,4
SUM=SUM+CL0(I,J)*X(J,L)
135 ASUMZ=ABS(SUM)
IF(NCONV.NE.1.OR. ASUMZ.LT.1.E-06) GO TO 134
DELZ=ABS(Z(I,L1)-SUM)
ZTEST=EPS*TZMAX(I,M0)
IF(DELZ.GT.ZTEST) NCONV=0
Z(I,L1)=SUM
134 LS=2
124 GO TO 150
END

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00002290
00002300
00002310
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00002330
00002340
00002350
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00002370
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00002500
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00002690
00002700

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C***** SUBROUTINE PLOT1(I) 0000010
C***** THIS SUBROUTINE CALLS PLOTTING ROUTINES FOR APPROPRIATE (USER) 0000020
C***** SPECIFIED) INPUT QUANTITIES 0000030
C***** IMPLICIT LOGICAL*1 ($) 0000040
C***** COMMON /IBL4/ KMAX,KL 0000050
C***** 1 IRADII, IGAMMA, IOMEGS, IOMEGT, IDEOMS, IBST IF, IDSTIF, 0000060
COMMON /BLPLOT/ 0000070
2 IBBSTIF, IDDSIF, IPR, IPS, IPT, ITT, IMT, IDTT, IDMT, INS, 0000080
3 INTH, INSTH, IQS, IMS, IMTH, IMSTH, IU, IV, IW, IPHIS, 0000090
COMMON /BLPLT1/ 0000100
1 XRADII(100), YGAMMA(100), YOMEGS(100), YOMEGT(100), 0000110
2 YDEOMS(100), YBSTIF(100), YDSTIF(100), YBBSTIF(100), 0000120
3 YDDSTF(100), YPR(100), YPS(100), YPT(100), YTT(100), 0000130
4 YMT(100), YDT(100), YDMT(100), YNS(100), YNTH(100), 0000140
5 YNSTH(100), YQS(100), YMS(100), YMTH(100), YMSTH(100), 0000150
6 YU(100), YV(100), YW(100), YPHIS(100), YPHIT(100), 0000160
YPHI(100), XSTATN(100) 0000170
C***** NGKMAX=-KMAX 0000180
IF (I.GT.1) GO TO 1 0000190
IF (IRADII.EQ.0) GO TO 2 0000200
WRITE (6,1000) 0000210
CALL PLOTIT (XSTATN,XRADII,NGKMAX,0) 0000220
WRITE (6,1001) 0000230
IF (IGAMMA.EQ.0) GO TO 4 0000240
WRITE (6,1000) 0000250
CALL PLOTIT (XSTATN,YGAMMA,NGKMAX,0) 0000260
WRITE (6,1002) 0000270
IF (IOMEGS.EQ.0) GO TO 5 0000280
WRITE (6,1000) 0000290
CALL PLOTIT (XSTATN,YOMEGS,NGKMAX,0) 0000300
WRITE (6,1003) 0000310
IF (IOMEGT.EQ.0) GO TO 6 0000320
WRITE (6,1000) 0000330
CALL PLOTIT (XSTATN,YOMEGT,NGKMAX,0) 0000340
WRITE (6,1004) 0000350
IF (IDEOMS.EQ.0) GO TO 7 0000360
WRITE (6,1000) 0000370
CALL PLOTIT (XSTATN,YDEOMS,NGKMAX,0) 0000380
WRITE (6,1005) 0000390
IF (IBSTIF.EQ.0) GO TO 8 0000400
WRITE (6,1000) 0000410
00000420

```



```

WRITE (6,1000)
CALL PLOTIT (XSTATN,YBSTIF,NGKMAX,0)
WRITE (6,1006)
8 IF (IDSTIF.EQ.0) GO TO 9
WRITE (6,1000)
CALL PLOTIT (XSTATN,YDSTIF,NGKMAX,0)
WRITE (6,1007)
9 IF (IBBSTF.EQ.0) GO TO 10
WRITE (6,1000)
CALL PLOTIT (XSTATN,YBBSTF,NGKMAX,0)
WRITE (6,1008)
10 IF (IDDSIF.EQ.0) GO TO 1
WRITE (6,1000)
CALL PLOTIT (XSTATN,YDDSTF,NGKMAX,0)
WRITE (6,1009)
1 IF (IPR.EQ.0) GO TO 11
WRITE (6,1000)
CALL PLOTIT (XSTATN,YPR,NGKMAX,0)
WRITE (6,1010)
11 IF (IPS.EQ.0) GO TO 12
WRITE (6,1000)
CALL PLOTIT (XSTATN,YPS,NGKMAX,0)
WRITE (6,1011)
12 IF (IPT.EQ.0) GO TO 13
WRITE (6,1000)
CALL PLOTIT (XSTATN,YPT,NGKMAX,0)
WRITE (6,1012)
13 IF (ITT.EQ.0) GO TO 14
WRITE (6,1000)
CALL PLOTIT (XSTATN,YTT,NGKMAX,0)
WRITE (6,1013)
14 IF (IMT.EQ.0) GO TO 15
WRITE (6,1000)
CALL PLOTIT (XSTATN,YMT,NGKMAX,0)
WRITE (6,1014)
15 IF (IDTT.EQ.0) GO TO 16
WRITE (6,1000)
CALL PLOTIT (XSTATN,YDTT,NGKMAX,0)
WRITE (6,1015)
16 IF (IDMT.EQ.0) GO TO 17
WRITE (6,1000)
CALL PLOTIT (XSTATN,YDMT,NGKMAX,0)
WRITE (6,1016)
WRITE (6,1000)
17 RETURN
C*****
1000 FORMAT ('1')
1001 FORMAT ('0',T10,'RADIUS VS STATION')

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00000430
00000440
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00000870
00000880
00000890
00000900

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1002 FORMAT ('0',T10,'GAMMA VS STATION',)
1003 FORMAT ('0',T10,'OMEGA-S VS STATION',)
1004 FORMAT ('0',T10,'OMEGA-THETA VS STATION',)
1005 FORMAT ('0',T10,'DEOMEGA-S VS STATION',)
1006 FORMAT ('0',T10,'B-STIFFNESS VS STATION',)
1007 FORMAT ('0',T10,'D-STIFFNESS VS STATION',)
1008 FORMAT ('0',T10,'DB-STIFFNESS VS STATION',)
1009 FORMAT ('0',T10,'DD-STIFFNESS VS STATION',)
1010 FORMAT ('0',T10,'NORMAL LOADING VS STATION',)
1011 FORMAT ('0',T10,'MERIDIO-TANGENTIAL LOADING VS STATION',)
1012 FORMAT ('0',T10,'CIRCUMFERENTIO-TANGENTIAL LOADING VS STATION',)
1013 FORMAT ('0',T10,'THERMAL LOADING VS STATION',)
1014 FORMAT ('0',T10,'THERMAL BENDING VS STATION',)
1015 FORMAT ('0',T10,'DE-THERMAL BENDING VS STATION',)
1016 FORMAT ('0',T10,'DE-THERMAL-BENDING VS STATION',)
C*****
END
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00001010
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C*****
SUBROUTINE PMATRIX *****
THIS SUBROUTINE CALLS THE SUBROUTINES HJ(K,MN), EFG(K,MN), ABC,
AND PANDD(K,MN) TO SET UP THE P, P-BAR AND P-HAT MATRICES GIVEN
BY EQUATIONS (30) OF REFERENCE (3).
INTERNALLY, MATRICES DL, DG AND DF ARE SET UP FOR THE CALCULA-
TION OF X(1) GIVEN BY EQUATION (31A) OF REF. (3), WHERE
X(1) = DL*SMALL-L(1) + DG*SMALL-G(1) + DF*SMALL-F(1)
THE SPECIAL P MATRIX FOR A SHELL WITH AN INITIAL POLE IS ALSO
COMPUTED HERE.
MATRICES ZF1M,ZF2M,ZF3M,ZF4M ARE SET UP FOR THE CALCULATION OF
Z(K+1) GIVEN BY EQUATION (31B) OF REF. (3), WHERE
Z(K+1)=ZF1M*SMALL-L(K) + ZF2M*X(K) + ZF3M*X(K-1) + ZF4M*SMALL-F
IF THE SHELL HAS A FINAL POLE, THE MATRICES CL0,CL1,CL2 ARE
PREPARED FOR THE CALCULATION OF Z(K)
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DO 6 L=1,4
SUMCB=SUMOB+POTA(I,L)*P8TA(L,J)
SUMDA=SUMOA+POTA(I,L)*PATA(L,J)
SUMDC=SUMOC+POTA(I,L)*C(L,J)
6 DLL(I,J)=SUMOB+PJA(I,J)+CAPL1(I,J)
PTR(I,J)=SUMOA
5 DGG(I,J)=SUMOC
CALL MATINV(DLL,4,PTR,4,DETERM,IPIVOT,INDEX,4,ISCALE)
DO 1 I=1,4
DO 1 J=1,4
SUMD=0.
SUME=0.
DO 7 L=1,4
SUMD=SUMD+DLL(I,L)*DGG(L,J)
7 SUME=SUME-DLL(I,L)*OMEG1(L,J)
DL(I,J,MN)=SUMD
DG(I,J,MN)=SUME
DF(I,J,MN)=SUME
IJ=1+KMAX*(MN-1)
1 P(I,J,IJ)=PTR(I,J)
GO TO 20
10 DO 11 MN=MNINIT,MNMAX
NN=IABS(N(MN))
IJ=1+KMAX*(MN-1)
DO 14 I=1,4
DO 14 J=1,4
X(I,IJ)=0.
DO 14 J=1,4
P(I,J,IJ)=0.
IF(NN.GT.3) GO TO 11
IF(NN.GT.2) GO TO 90
IF(NN.GT.1) GO TO 12
IF(NN.GT.0) GO TO 13
P(3,3,IJ)=-1.
P(4,4,IJ)=-1.
M0=MN
GO TO 11
12 P(4,4,IJ)=-1.
M2=MN
GO TO 11
90 M3=MN
GO TO 11
13 P(1,1,IJ)=-1.
P(2,1,IJ)=1.
IF(N(MN).LT.0) P(2,1,IJ)=-1.
M1=MN
11 CONTINUE
20 KLAST=KMAX
IF(IBCFLN.LT.0) KLAST=KL

```



```

DO 23 K=2,KLAST
DO 23 MN=MNINIT,MNMAX
CALL EFG(K,MN)
CALL ABC
CALL PANDD(K,MN)
IF(IBCENL.LT.O) GO TO 30
DO 40 MN=MNINIT,MNMAX
IKL=MN*KMAX-1
JKL=KMAX*MN
CALL HJ(KMAX,MN)
DO 41 I=1,4
DO 41 J=1,4
SUMO=0.
SUMP=0.
SUMJ=0.
DO 42 L=1,4
SUMO=SUMO+OMEG(L,I,L)*H(L,J)
SUMP=SUMP+P(I,L,IKL)*P(L,J,JKL)
SUMJ=SUMJ+OMEG(L,I,L)*JAY(L,J)
PATA(I,J)=SUMO
PBTA(I,J)=UNIT(I,J)-SUMP
PJTA(I,J)=SUMJ+CAPLL(I,J)
DO 43 I=1,4
DO 43 J=1,4
SUMOP=0.
SUMJP=0.
SUMCM=0.
DO 44 L=1,4
SUMOP=SUMOP+PATA(I,L)*PBTA(L,J)
SUMJP=SUMJP+PJTA(I,L)*P(L,J,JKL)
SUMCM=SUMCM-PATA(I,L)*P(L,J,IKL)
ZF1(I,J)=SUMOP-SUMJP
ZF2(I,J)=SUMCM-PJTA(I,J)
CALL MATINV(ZF1,4,ZF2,4,DETERM,PIVOT,INDEX,4,ISCALE)
DO 45 I=1,4
DO 45 J=1,4
SZF3=0.
SZF4=0.
DO 46 L=1,4
SZF3=SZF3+ZF1(I,L)*PATA(L,J)
SZF4=SZF4-ZF1(I,L)*OMEG(L,I,J)
ZF3M(I,J,MN)=SZF3
ZF4M(I,J,MN)=SZF4
ZF1M(I,J,MN)=ZF1(I,J)
ZF2M(I,J,MN)=ZF2(I,J)
CONTINUE
RETURN
DO 31 MN=MNINIT,MNMAX

```





```

IKL=MN*KMAX-1
NN=IABS(N(MN))
IF(NN.GT.3) GO TO 31
IF(NN.GT.2) GO TO 300
IF(NN.GT.1) GO TO 33
IF(NN.GT.0) GO TO 34
MO=MN
DO 35 J=1,4
DO 35 I=1,4
CLO(I,J)=0.
ZFPO(I,J)=0.
ZFPO(1,1)=1.
ZFPO(2,2)=1.
ZFPO(3,1)=P(3,1,IKL)
ZFPO(3,2)=P(3,2,IKL)
ZFPO(3,3)=P(3,3,IKL)+1.
ZFPO(3,4)=P(3,4,IKL)
ZFPO(4,1)=P(4,1,IKL)
ZFPO(4,2)=P(4,2,IKL)
ZFPO(4,3)=P(4,3,IKL)
ZFPO(4,4)=P(4,4,IKL)+1.
CLO(3,3)=1.
CLO(4,4)=1.
CALL MATINV(ZFPO,4,CLO,4,DETERM,IPIVOT,INDEX,4,ISCALE)
GO TO 31
300 M3=MN
GO TO 31
34 M1=MN
DO 60 J=1,4
DO 60 I=1,4
CLO(I,J)=0.
ZFPI(I,J)=0.
ZFPI(1,1)=P(1,1,IKL)+1.
ZFPI(1,2)=P(1,2,IKL)
ZFPI(1,3)=P(1,3,IKL)
ZFPI(1,4)=P(1,4,IKL)
ZFPI(2,1)=1.
ZFPI(2,2)=-1.
ZFPI(2,3)=1.
ZFPI(3,3)=1.
ZFPI(4,4)=1.
CLO(1,1)=1.
CALL MATINV(ZFPI,4,CLO,4,DETERM,IPIVOT,INDEX,4,ISCALE)
GO TO 31
33 M2=MN
DO 70 J=1,4
DO 70 I=1,4
CLO(I,J)=0.

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70 ZFP2(I,J)=0.
   ZFP2(1,1)=1.
   ZFP2(2,2)=1.
   ZFP2(3,3)=1.
   ZFP2(4,1)=P(4,1,IKL)
   ZFP2(4,2)=P(4,2,IKL)
   ZFP2(4,3)=P(4,3,IKL)
   ZFP2(4,4)=P(4,4,IKL)+1.
   CL2(4,4)=1.
   CALL MATINV(ZFP2,4,CL2,4,DETERM,IPIVOT,INDEX,4,ISCALE)
31 CONTINUE
   RETURN
   END

```

```

C***** SUBROUTINE UPDATE
C***** THIS SUBROUTINE UPDATES THE STORAGE LOCATIONS OF THE BETA'S AND
C***** ETA'S. IT IS CALLED IN SUBROUTINE XANDZ AFTER A MERIDIAN
C***** STATION CHANGE.
C*****
C***** COMMON /IBL1/ MNMAX
C***** COMMON /BL27/ BX3(10),BT3(10),BXI3(10),BE3(10)
C***** COMMON /BL28/ EXX3(10),ETX3(10),EXT3(10),EX3(10),ET3(10)
C***** COMMON /BL29/ BXT1(10),BT1(10),BXT1(10),BX2(10),BT2(10),
C***** 1 BXT2(10),BE2(10)
C***** 1 EXX1(10),ETX1(10),EXT1(10),EX1(10),ET1(10),EXX2(10),
C***** 1 ETX2(10),EXT2(10),EX2(10),ET2(10)
C***** COMMON /BL31/ DELSQ,EXT1(10)
C***** DO 1 M=1,MNMAX
C***** 1 BX1(M)=BX2(M)
C***** 1 BT1(M)=BT2(M)
C***** 1 BXT1(M)=BXT2(M)
C***** 1 BE1(M)=BE2(M)
C***** 1 BX2(M)=BX3(M)
C***** 1 BT2(M)=BT3(M)
C***** 1 BXT2(M)=BXT3(M)

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BE2(M)=BE3(M)
EXX1(M)=EXX2(M)
ETT1(M)=ETT2(M)
ETX1(M)=ETX2(M)
EXT1(M)=EXT2(M)
EX1(M)=EX2(M)
ET1(M)=ET2(M)
EXX2(M)=EXX3(M)
ETT2(M)=ETT3(M)
ETX2(M)=ETX3(M)
EXT2(M)=EXT3(M)
EX2(M)=EX3(M)
ET2(M)=ET3(M)
1 RETURN
END

```

```

SUBROUTINE INLPOL
C*****
C THIS SUBROUTINE COMPUTES THE NON-LINEAR TERMS BETA-SUB S,
C -SUB THETA, -SUB S-THETA, AETA-SUB S-S AND -SUB THETA-S AT AN
C INITIAL POLE.
C*****
COMMON /IBL1/ MNMAX
COMMON /IBL3/ M0,M1,M2,M3
COMMON /IBL12/ KMAX1,KMAX2,NCONV
COMMON /IBL13/ ITRMAX,LSMAX
COMMON /BL5/ T(10),EMT(10),DT(10),DMT(10)
COMMON /BL6/ Z(4,220),SOE,OSE,ALOAD
COMMON /BL7/ D1,S1
COMMON /BL11/ OMXI(200),PHEE,T0,T2
COMMON /BL17/ DEL
COMMON /BL29/ BX1(10),BT1(10),BXT1(10),BE1(10),BX2(10),BT2(10),
1 BXT2(10),BE2(10)
COMMON /BL30/ EXX1(10),ETT1(10),ETX1(10),ET1(10),EXX2(10),
1 ETT2(10),ETX2(10),EXT2(10),ET2(10)
COMMON /BL31/ DELSQ,EXT1(10)
C*****
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00000200
00000210
00000220

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DO 1 MN=1, MNMAX
BX1 (MN)=0.
BT1 (MN)=0.
BXT1 (MN)=0.
BE1 (MN)=0.
EX1 (MN)=0.
ET1 (MN)=0.
ETX1 (MN)=0.
EXX1 (MN)=0.
RETURN
1 IF (M1.EQ.0) RETURN
I2=2+(M1-1)*KMAX2
I3=I2+1
I4=I3+1
PHEE=(1.5*Z(3,I2)-2.*Z(3,I3)+.5*Z(3,I4))/DEL+OMXI(1)*Z(1,I2)
BET=.5*PHEE**2
IF (ITRMAX.EQ.1) BET=0.
T2=0.
IF (M2.EQ.0) GO TO 2
CALL BDB(1,B,DB,D,DD)
I2=2+(M2-1)*KMAX2
I3=I2+1
I4=I3+1
T2=B**DI*((-1.5*Z(1,I2)+2.*Z(1,I3)-.5*Z(1,I4))/DEL+.5*SOE*BET)
Q1=.5*PHEE*T2
BX1 (M2)=BET
BT1 (M2)=-BET
BXT1 (M2)=-BET
ETX1 (M1)=Q1
IF (M3.EQ.0) GO TO 2
EXX1 (M3)=Q1
ETX1 (M3)=-Q1
T0=0.
2 IF (M0.EQ.0) GO TO 3
BX1 (M0)=BET
BT1 (M0)=BET
CALL BDB(1,B,DB,D,DD)
CALL TLOAD(1)
I2=2+(M0-1)*KMAX2
I3=I2+1
I4=I3+1
T0=B**S1*((-1.5*Z(1,I2)+2.*Z(1,I3)-.5*Z(1,I4))/DEL+OMXI(1)*Z(3,I2)
1+.5*SOE*BET)-TT(M0)*ALOAD
3 EXX1 (M1)=PHEE*(T0+.5*T2)
RETURN
END

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SUBROUTINE FNLPOL
C*****
C      THIS SUBROUTINE COMPUTES THE NON-LINEAR TERMS BETA-SUB S, AT A
C      -SUB THETA, -SUB S-THETA, AETA-SUB S-S, AND -SUB THETA-S
C      FINAL POLE.
C*****
COMMON /IBL1/ MNMAX
COMMON /IBL3/ MO,M1,M2,M3
COMMON /IBL4/ KMAX,KL
COMMON /IBL12/ KMAX1,KMAX2,NCONV
COMMON /IBL13/ ITRMAX,LSMAX
COMMON /BL5/ TT(10),EMT(10),DT(10),DMT(10)
COMMON /BL6/ Z(4,220),SOE,OSE,ALOAD
COMMON /BL7/ D1,S1
COMMON /BL11/ OMXI(200),PHEE,TO,T2
COMMON /BL17/ DEL
COMMON /BL27/ BX3(10),BT3(10),BXI3(10),BE3(10)
COMMON /BL28/ EXX3(10),ETI3(10),ETX3(10),ETI3(10),ETX3(10)
C*****
DO 1 MN=1,MNMAX
  BX3(MN)=0.
  BT3(MN)=0.
  BXI3(MN)=0.
  BE3(MN)=0.
  EX3(MN)=0.
  ETI3(MN)=0.
  ETX3(MN)=0.
  EXX3(MN)=0.
  CALL BDB(KMAX,B,DB,D,DB)
  IF(M1.EQ.0) RETURN
  KM=KMAX1+(M1-1)*KMAX2
  KM1=KM-1
  KM2=KM-2
  PHEE=-(1.5*Z(3,KM)-2.*Z(3,KM1)+.5*Z(3,KM2))/DEL+OMXI(KMAX)*Z(1,KM)
  BET=.5*PHEE**2
  IF(ITRMAX.EQ.1) BET=0.
  T2=0.
  IF(M2.EQ.0) GO TO 2
  KM=KMAX1+(M2-1)*KMAX2

```



```

KM1=KM-1
KM2=KM-2
T2=B*D1*((1.5*Z(1,KM)-2.*Z(1,KM1)+.5*Z(1,KM2))/DEL+.5*SOE*BET)
Q1=.5*PHEE*T2
BX3(M2)=BET
BT3(M2)=-BET
BXT3(M2)=BET
ETX3(M1)=Q1 GO TO 2
IF(M3.EQ.0) GO TO 2
EXX3(M3)=Q1
ETX3(M3)=-Q1
T0=0
2 IF(MJ.EQ.0) GO TO 3
CALL TLOAD(KMAX)
KM=KMAX1+(M0-1)*KMAX2
KM1=KM-1
KM2=KM-2
BX3(M0)=BET
BT3(M0)=BET
T0=B*S1*((1.5*Z(1,KM)-2.*Z(1,KM1)+.5*Z(1,KM2))/DEL+OMXI(KMAX)*
1 Z(3,KM)+.5*SOE*BET)-TT(M0)*ALOAD
3 EXX3(M1)=PHEE*(T0+.5*T2)
RETURN
END

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SUBROUTINE PHIBET(K)
C *** THIS SUBROUTINE CALCULATES THE PHI'S AND CARRIES OUT THE
C *** MULTIPLYING AND SUMMATION PROCEDURE FOR COMPUTING THE BETA
C *** NON-LINEAR TERMS FOR A GIVEN MERIDIONAL STATION K. THE ARRAYS
C *** IS, JS, ID, JS, IJS, MAXS, MAXD, MAXSY ARE PREPARED IN SUB-
C *** ROUTINE MODES AND USED HERE.
C *** COMMON /IBL1/ MNMAX
C *** COMMON /IBL2/ N(10),MNINIT
C *** COMMON /IBL4/ KMAX,KL
C *** COMMON /IBL7/ MNMAXO,MAXD(10),MAXS(10),MAXSY(10),IS(10,10),
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1 COMMON /IBL12/ JS(10,10),ID(10,10),JD(10,10),IJS(10)
COMMON /IBL13/ KMAX1,KMAX2,NCONV
COMMON /BL6/ Z(4,220),SOE,OSE,ALOAD
COMMON /BL8/ R(200),GAM(200),OMT(200)
COMMON /BL10/ PHIX(10),PHIT(10),PHI(10)
COMMON /BL11/ OMXI(200),PHEE,T0,T2
COMMON /BL12/ TDLI,TDEL
COMMON /BL15/ NU,U1(10),V1(10),V2(10),U2(10),W2(10),U3(10),
1 COMMON /BL27/ BX3(10),BT3(10),BXT3(10),BE3(10)
C*****
OX=OMXI(K)
OT=OMT(K)
RRA=1./R(K)
GA=GAM(K)
KP2=K+2
DO 1 M=1,MNMAXO
EN=N(M)
IK=KP2+(M-1)*KMAX2
U3(M)=Z(1,IK)
V3(M)=Z(2,IK)
W3(M)=Z(3,IK)
PHIX(M)=-TDLI*(W3(M)-W1(M))+OX*U2(M)
PHIT(M)=EN*W2(M)*RRA+V2(M)*OT
PHI(M)=(TDLI*(V3(M)-V1(M))+GA*V2(M)+EN*U2(M)*RRA)*.5
1 IF(1TRMAX.EQ.1) RETURN
DO 9 M=1,MNMAX
SMO=0.
SMT=0.
SMR=0.
SMF=0.
IF(N(M).EQ.0) GO TO 20
MAXL=MAXS(M)
IF(MAXL.EQ.0) GO TO 2
DO 3 L=1,MAXL
I=IS(L,M)
J=JS(L,M)
SMO=SMO+PHIX(I)*PHIX(J)
SMT=SMT-PHIT(I)*PHIT(J)
SMR=SMR+PHIX(I)*PHIT(J)+PHIX(J)*PHIT(I)
SMF=SMF-PHI(I)*PHI(J)
3 MAXL=MAXD(M)
2 IF(MAXL.EQ.0) GO TO 4
DO 5 L=1,MAXL
I=ID(L,M)
J=JD(L,M)
SMO=SMO+PHIX(I)*PHIX(J)

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SMT=SMT+PHIT(I)*PHIT(J)
SMR=SMR-PHIX(I)*PHIT(J)+PHIX(J)*PHIT(I)
5 SMF=SMF+PHI(I)*PHI(J)
4 IF(MAXSY(M).EQ.0) GO TO 10
I=IJS(M)
SMO=SMO+PHIX(I)**2/2.
SMT=SMT-PHIT(I)**2/2.
SMR=(SMR+PHIX(I)*PHIT(I))
SMF=SMF-PHI(I)**2/2.
GO TO 10
20 DO 21 L=1,MNMA XO
SMO=SMO+PHIX(L)**2
SMT=SMT+PHIT(L)**2
21 SMF=SMF+PHI(L)**2
IF(M.GT.MNMAXO) GO TO 11
SMO=SMO+PHIX(M)**2
11 BX3(M)=SMO*.5
BT3(M)=SMT*.5
BE3(M)=SMF*.5
BXT3(M)=0.
GO TO 9
10 BX3(M)=SMO
BT3(M)=SMT
BXT3(M)=SMR*.5
BE3(M)=SMF
9 CONTINUE
RETURN
END

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SUBROUTINE EFG(K,MN)
C*****
C THIS SUBROUTINE PREPARES THE ELEMENTS OF THE E, F, AND G
C FOR EACH MERIDIAN STATION K AND FOR EACH FOURIER MODE, MN.
C*****
IMPLICIT LOGICAL*1(I)
REAL NU,N,LAM2,LSD18,LSD1N,MAS
COMMON /IBL2/NN(10),MNINIT
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COMMON /BL8/ R(200),GAM(200),OMT(200)
COMMON /BL11/ OMT(200),PHEE,T0,T2
COMMON /BL14/ LAM2,LS18,LS19
COMMON /BL15/ NU,U1(10),V1(10),W1(10),U2(10),W2(10),U3(10),
1 V3(10),W3(10)
COMMON /BL20/ DEOMX(200)
COMMON /BL25/ E(4,4),F(4,4),G(4,4)
COMMON /BL100/ TEO,$DYNMC
COMMON /BL101/ ZO(4,220),Z2(4,220),Z3(4,220),DELS
COMMON /BL102/ DELOAD
COMMON /BL103/ MASS(200)
C *****
N=NN(MN)
MASS=MASS(K)
CALL BDB(K,B,DB,D,DD)
E(1,1)=B
E(1,2)=0.
E(1,3)=0.
E(1,4)=0.
E(2,1)=0.
D1=(1.-NU)
RA=R(K)
GA=GAM(K)
OX=OMT(K)
OT=OMT(K)
DEX=DEOMX(K)
GAX=GA**2
RXE=(3.*OX-OT)
OTX=OT*OX
DNLR=LAM2*D*N*D1/(2.*RA)
DDNLR=DNLR*DD/D
E(2,2)=B*D1/2.+LAM2*D*D1*REX**2/8.
E(2,3)=DNLR*REX
E(2,4)=J.
E(3,1)=0.
E(3,2)=E(2,3)
RAN=(N/RA)**2
E(3,3)=LAM2*D*D1*(2.*RAN+(1.+NU)*GA2)
E(3,4)=LAM2
E(4,1)=0.
E(4,2)=0.
E(4,3)=-D
E(4,4)=0.
F(1,1)=GA*B+DB
F(1,2)=(1.+NU)*B*N/(2.*RA)+DNLR*REX*RXE/4.
F(1,3)=B*(OX+NU*OT)+LAM2*D*D1*((1.+NU)*GA2*OX+RAN*REX/2.)
F(1,4)=LAM2*OX
00000090
00000100
00000110
00000120
00000130
00000140
00000150
00000160
00000170
00000180
00000190
00000200
00000210
00000220
00000230
00000240
00000250
00000260
00000270
00000280
00000290
00000300
00000310
00000320
00000330
00000340
00000350
00000360
00000370
00000380
00000390
00000400
00000410
00000420
00000430
00000440
00000450
00000460
00000470
00000480
00000490
00000500
00000510
00000520
00000530
00000540
00000550
00000560

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```

F(2,1)=-F(1,2)
F(2,2)=(D1/2.)*(GA*B+DB)-(LAM2*D*D1*REX/8.)*(2.*DEX-GA*(5.*OX
1-F(2,3))+LAM2*DD*D1*REX**2/8.
F(2,3)=DNLR*(2.*(1.+NU)*GA*OT-DEX+3.*GA*(OX-OT))+DNLR*REX
F(2,4)=0.
F(3,1)=-F(1,3)
F(3,2)=DNLR*(3.*GA*OX-GA*OT*(5.+2.*NU)-DEX)+DDNLR*REX
F(3,3)=-LAM2*D*D1*(1.+NU)*(2.*GA*OX*OT+GA**3)+2.*GA*GAN)
1+LAM2*DD*D1*(1.+NU)*GA2+2.*GAN)
F(3,4)=LAM2*GA*(2.-NU)
F(4,1)=D*OX
F(4,2)=0.
F(4,3)=-D*NU*GA
F(4,4)=0.
G(1,1)=NU*DB*GA-NU*B*OTX-B*GA2-D1*B*GAN/2.-LAM2*D*D1*((1.+NU)*GA2*
1OX**2+RXE**2*GAN/8.)
2-2.*MAS/DELS
G(1,2)=NU*DB/RA-(3.-NU)/(2.*RA)*GA*B*GAN-DNLR*2.*GA*(REX*RXE/8.
1+(1.+NU)*OTX)
G(1,3)=B*(DEX+GA*(OX-OT))+DB*(OX+NU*OT)-LAM2*D*D1*GA*GAN*(RXE/2.+(
11.+NU)*OX)
G(1,4)=LAM2*D1*GA*OX
G(2,1)=-B*GAN*(3.-NU)/(2.*RA)-D1*GAN*DB/(2.*RA)+DNLR*2.*(-1.*(1.+
1NU)*GA*OTX+GA/8.*(6.*OTX-7.*OX**2-3.*OT**2)-DEX/4.*(5.*OT-3.*OX))
2-DDNLR/4.*REX*RXE
G(2,2)=-GA*F(2,2)+D1/2.*B*OTX-B*GAN-LAM2*D*D1*((1.+NU)*OT**2*GAN
1-OTX/8.*REX**2)
2-2.*MAS/DELS
G(2,3)=-B*GAN*(OT+NU*OX)/RA+DNLR*(GA*DEX-2.*GA2*OX-2.*(1.+NU)*OT
1*GAN+REX*(GA2+OTX))-DDNLR*REX*GA
G(2,4)=-NU*LAM2*OT*GAN/RA
G(3,1)=-B*GA*(OT+NU*OX)+LAM2*D*D1*(GA*(1.+NU)*(-GA*DEX+GA2*GX
1-OX*GAN+2.*OTX*OX)+GAN/2.*(GA*OX-GA*OT-3.*DEX))
2-LAM2*DD*D1*((1.+NU)*GA2*OX+GAN/2.*RXE)
G(3,2)=-B*GAN*(OT+NU*OX)/RA+DNLR*(2.*(1.+NU)*(OTX*OT-GA2*OX+2.*GA2
1*OT-OT*GAN)+GA*DEX+3.*GA2*(OT-OX)+OTX*REX)-DDNLR*(2.*(1.+NU)*GA
2*OT+GA*REX)
G(3,3)=-B*GAN*(OX**2+2.*NU*OTX+OT**2)+LAM2*D*D1*GAN*((1.+NU)*(OTX-RAN
1+2.*GA2)+2.*(GA2+OTX))-LAM2*DD*D1*GAN*(3.+NU)*GA
2-2.*MAS/DELS
G(3,4)=-LAM2*(D1*OTX+NU*GAN)
G(4,1)=D*(DEX+NU*GA*OX)
G(4,2)=D*(DEX*NU*OT/RA
G(4,3)=D*NU*GAN
G(4,4)=-1.
RETURN
END

```



```

C***** SUBROUTINE TEAETA(K)
C***** THIS SUBROUTINE CALCULATES THE INPLANE FORCES AND CARRIES OUT
C***** THE MULTIPLYING AND SUMMATION PROCEDURE FOR COMPUTING THE AETA
C***** NON-LINEAR TERMS FOR A GIVEN MERIDIONAL STATION K. THE ARRAYS
C***** IS, JS, ID, JS, IJS, MAXS, MAXD, MAXSY PREPARED IN SUBROUTINE
C***** MODES ARE USED HERE
C*****
C***** REAL NU, MT
COMMON /IBL1/ MNMAX
COMMON /IBL2/ N(10), MNINIT
COMMON /IBL7/ MNMAXO, MAXD(10), MAXS(10), MAXSY(10), IS(10,10),
1 JS(10,10), ID(10,10), JD(10,10), IJS(10,10)
COMMON /IBL8/ LSTEP, ITR
COMMON /IBL13/ ITRMAX, LS MAX
COMMON /BL5/ TT(10), MT(10), DT(10), DMT(10)
COMMON /BL6/ Z(4,220), SOE, OSE, ALOAD
COMMON /BL7/ D1, S1
COMMON /BL8/ R(200), GAM(200), OMT(200)
COMMON /BL10/ PHIX(10), PHIT(10), PHI(10)
COMMON /BL11/ QMXI(200), PHEE, TO, T2
COMMON /BL12/ TDL1, TDEL
COMMON /BL15/ NU, U1(10), V1(10), V2(10), U2(10), W2(10), U3(10),
1 V3(10), W3(10)
COMMON /BL27/ BX3(10), BT3(10), BXI3(10), BE3(10)
COMMON /BL28/ EXX3(10), ETI3(10), ETX3(10), EX3(10), ET3(10)
C***** DIMENSION TX(10), TTH(10), THT(10)
C*****
C***** RA=1./R(K)
C***** GA=GAM(K)
C***** OX=OMXI(K)
C***** OT=OMT(K)
C***** CALL BDB(K, BS, DB, DS, DD)
C***** DO 1 M=1, MNMAXO
C***** EN=N(M)
C***** CALL TLOAD(K)
C***** TTS=TT(M)*ALOAD
C*****
00000010
00000020
00000030
00000040
00000050
00000060
00000070
00000080
00000090
00000100
00000110
00000120
00000130
00000140
00000150
00000160
00000170
00000180
00000190
00000200
00000210
00000220
00000230
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00000370

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EX=(U3(M)-U1(M))*TDLI+OX*W2(M)+OSE*(BX3(M)+BE3(M))
ET= EN *V2(M)*RRA+GA*U2(M)+OT*W2(M)+OSE*(BT3(M)+BE3(M))
EXT=.5*(TDLI*(V3(M)-V1(M))- EN *U2(M)*RRA-GA*V2(M))+OSE*BT3(M)
TX(M)=BS*(EX+NU*ET)-TTS
TTH(M)=BS*(ET+NU*EX)-TTS
1 TX(M)=BS*D1*EXT
DO 9 M=1,MNMAX
SMF=0.
SMS=0.
SMV=0.
SME=0.
SMN=0.
SMT=0.
IF(N(M).EQ.0) GO TO 20
MAXL=MAXS(M)
IF(MAXL.EQ.0) GO TO 2
DO 3 L=1,MAXL
I=IS(L,M)
J=JS(L,M)
SMF=SMF+TX(I)*PHIX(J)+TX(J)*PHIX(I)
SMS=SMS+TTH(I)*PHIT(J)+TTH(J)*PHIT(I)
SMV=SMV+PHIT(I)*TXT(J)-PHIT(J)*TXT(I)
SME=SME+PHIX(I)*TXT(J)+PHIX(J)*TXT(I)
SMN=SMN+TX(I)*PHI(J)+TX(J)*PHI(I)
SMT=SMT+TTH(I)*PHI(J)+TTH(J)*PHI(I)
3 MAXL=MAXD(M)
IF(MAXL.EQ.0) GO TO 4
DO 5 L=1,MAXL
I=ID(L,M)
J=JD(L,M)
SMF=SMF+TX(I)*PHIX(J)+TX(J)*PHIX(I)
SMS=SMS+TTH(I)*PHIT(J)+TTH(J)*PHIT(I)
SMV=SMV+PHIT(I)*TXT(J)+PHIT(J)*TXT(I)
SME=SME+PHIX(I)*TXT(J)+PHIX(J)*TXT(I)
SMN=SMN+TX(I)*PHI(J)+TX(J)*PHI(I)
SMT=SMT+TTH(I)*PHI(J)+TTH(J)*PHI(I)
5 IF(MAXSY(M).EQ.0) GO TO 10
I=IJS(M)
SMF=SMF+TX(I)*PHIX(I)
SMS=SMS+TTH(I)*PHIT(I)
SMV=SMV+PHIT(I)*TXT(I)
SME=SME+PHIX(I)*TXT(I)
SMN=SMN+TX(I)*PHI(I)
SMT=SMT+TTH(I)*PHI(I)
4 GO TO 10
DO 21 L=1,MNMAX
SMF=SMF+TX(L)*PHIX(L)
21 SMV=SMV+PHIT(L)*TXT(L)

```





```

IF(M.GT.MNMAXO) GO TO 10
SMF=SMF+TX(M)*PHIX(M)
10 EXX3(M)=SMF*.5
   ETT3(M)=SMF*.5
   ETX3(M)=SMV*.5
   EXT3(M)=SME*.5
   EX3(M)=SMN*.5
   ET3(M)=SMT*.5
9  CONTINUE
   DO 30 M=1,MNMAXO
   U1(M)=U2(M)
   V1(M)=V2(M)
   W1(M)=W2(M)
   U2(M)=U3(M)
   V2(M)=V3(M)
   W2(M)=W3(M)
30 RETURN
END

```

```

00000860
00000870
00000880
00000890
00000900
00000910
00000920
00000930
00000940
00000950
00000960
00000970
00000980
00000990
00001000
00001010
00001020
00001030

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# APPENDIX F

## LISTING OF SATANS-II MODIFIED SUBROUTINES AND COMMON STATEMENTS

AS INDICATED IN THE BODY OF THIS REPORT, REPLACE THE FOLLOWING COMMON STATEMENTS  
IN ALL SUBROUTINES WHERE THEY OCCUR.

```

COMMON /IBL2/ N(25),MN,INIT
COMMON /IBL7/ MNMAXO,MAXD(25),MAXS(25),MAXSY(25),IS(25,25),
1 JS(25,25),ID(25,25),JD(25,25),IJS(25)
COMMON /IBL11/ ICORFL,IPASS,JUMP,MPERFS
COMMON /BL3/ PR(25),PX(25),PT(25)
COMMON /BL4/ P(4,4,951),X(4,951),ZF1M(4,4,25),ZF2M(4,4,25),
1 ZF3M(4,4,25),ZF4M(4,4,25)
COMMON /BL5/ TT(25),MT(25),DT(25),DMT(25)
COMMON /BL6/ Z(4,1001),SOE,OSE,ALOAD
COMMON /BL8/ R(100),GAM(100),OMT(100)
COMMON /BL9/ FFS(4,25),ELIS(4),GEES(4,25)
COMMON /BL10/ PHIX(25),PHIT(25),PHI(25)
COMMON /BL11/ OMXI(100),PHEE,T0,T2
COMMON /BL15/ NU,U1(25),V1(25),W1(25),V2(25),U2(25),W2(25),U3(25),
1 V3(25),W3(25)
COMMON /BL20/ DEOMX(100)
COMMON /BL24/ DL(4,4,25),DG(4,4,25),DF(4,4,25)
COMMON /BL27/ BX3(25),BT3(25),BXT3(25),BE3(25)
COMMON /BL28/ EXX3(25),ETT3(25),ETX3(25),EXT3(25),ET3(25)
COMMON /BL29/ BX1(25),BT1(25),BXT1(25),BE1(25),BX2(25),BT2(25),
1 BXT2(25),BE2(25)
COMMON /BL30/ EXX1(25),ETT1(25),ETX1(25),EX1(25),ET1(25),EXX2(25),
1 ETT2(25),ETX2(25),EX2(25),ET2(25)
COMMON /BL31/ DELSQ,EXT1(25)
COMMON /BL34/ DEE(4,4,951),DST(4,4,951)
COMMON /BL101/ ZO(4,1001),Z2(4,1001),Z3(4,1001),DELSO
COMMON /BL103/ MASS(100)
COMMON /BL104/ ZDOT(4,1001)
COMMON /BL110/ TX(25),TTH(25),TXT(25),MX(25),MTH(25),MXT(25),
1 QS(25)

```



AS INDICATED IN THE BODY OF THIS REPORT, REPLACE SUBROUTINES TEAETA, PHIBET, MODES, OUTPUT, INLPOL, FNLPOL AND POLE IN APPENDIX E WITH THOSE THAT FOLLOW.

```

SUBROUTINE TEAETA(K)
C*****
C      THIS SUBROUTINE CALCULATES THE INPLANE FORCES AND CARRIES OUT
C      THE MULTIPLYING AND SUMMATION PROCEDURE FOR COMPUTING THE AETA*
C      NON-LINEAR TERMS FOR A GIVEN MERIDIONAL STATION K. THE ARRAYS
C      ,IS, ,JS, ,ID, ,JD, ,IJS, ,MAXS, ,MAXD, , AND ,MAXSY, PREPARED
C      IN SUBROUTINE MODES ARE USED HERE
C*****
C      REAL NU, MT
COMMON /IBL1/ MNMAX
COMMON /IBL2/ N(25), MNINIT
COMMON /IBL7/ MNMAXO, MAXD(25), MAXS(25), MAXSY(25), IS(25, 25),
1 JS(25, 25), ID(25, 25), JD(25, 25), IJS(25)
COMMON /IBL8/ LSTEP, ITR
COMMON /IBL11/ ICORFL, IPASS, JUMP, MPERFS
COMMON /IBL13/ ITRMAX, LSMAX
COMMON /BL5/ TT(25), MT(25), DT(25), DMT(25)
COMMON /BL6/ Z(4, 1001), SOE, OSE, ALOAD
COMMON /BL7/ D1, S1
COMMON /BL8/ R(100), GAM(100), OMT(100)
COMMON /BL10/ PHIX(25), PHIT(25), PHI(25)
COMMON /BL11/ OMXI(100), PHEE, TO, T2
COMMON /BL12/ TDLI, TDEL
COMMON /BL15/ NU, U1(25), U2(25), U3(25), V1(25), V2(25), V3(25), W1(25),
1 W2(25), W3(25)
COMMON /BL27/ BX3(25), BT3(25), BX3(25), BE3(25)
COMMON /BL28/ EXX3(25), ETX3(25), ETX3(25), EX3(25), ET3(25)
COMMON /BLPHS/ PHX(25), PHT(25)
C*****
C      DIMENSION TX(25), TTH(25), TXT(25)
RRA=1./R(K)
GA=GAM(K)
OX=OMXI(K)
OT=OMT(K)
CALL BDB(K, BS, DB, DS, DD)
DO 1 M=1, MNMAXO
PHIX(M)=PHIX(M)+PHX(M)
PHIT(M)=PHIT(M)+PHT(M)
EN=N(M)
CALL TLOAD(K)
00000010
00000020
00000030
00000040
00000050
00000060
00000070
00000080
00000090
00000100
00000110
00000120
00000130
00000140
00000150
00000160
00000170
00000180
00000190
00000200
00000210
00000220
00000230
00000240
00000250
00000260
00000270
00000280
00000281
00000290
00000300
00000310
00000320
00000330
00000340
00000350
00000360
00000370
00000380
00000390

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C *** TEST FOR PRESENCE OF SYMMETRIC SUMMATION COMBINATIONS *** 00001360
C *** IF (MAXL.EQ.0) GO TO 2 *** 00001370
C *** SET UP COUPLING MODES, INDICES AND TEST FOR MODE 1 *** 0001380
C *** DO 3 L=1,MAXL *** 00001390
C *** I=IS(L,M) *** 00001400
C *** J=JS(L,M) *** 00001410
C *** IJ=I-1 *** 00001420
C *** JJ=J-1 *** 00001430
C *** IF (I.EQ.1) GO TO 3 *** 00001440
C *** COMPARE SUMS FOR SYMMETRIC SUM COMBINATION MODES *** 00001450
C *** SMF=SMF+TX(I)*PHIX(J)+TX(J)*PHIX(I)-PHIX(I)*TX(J) *** 00001460
C *** 1 SMS=SMS+TX(I)*PHIX(J)+TTH(J)*PHIT(I)+PHIT(I)*TTH(J) *** 00001470
C *** 1 SMV=SMV-PHIT(I)*PHIT(J)-PHIT(J)*TX(T(I))+PHIT(I)*TX(T(J)) *** 00001480
C *** 1 SME=SME+PHIX(I)*TX(T(J))+PHIX(J)*TX(T(I))+PHIX(I)*TX(T(J)) *** 00001490
C *** 1 SMN=SMN+TX(I)*PHI(J)+TX(J)*PHI(I)*TX(JJ) *** 00001500
C *** 1 SMT=SMT+TTH(I)*PHI(J)+TTH(J)*PHI(I)+PHI(I)*TTH(JJ) *** 00001510
C *** 3 CONTINUE *** 00001520
C *** 2 MAXL=MAXD(M) *** 00001530
C *** TEST FOR PRESENCE OF SYMMETRIC DIFFERENCE COMBINATIONS *** 00001540
C *** IF (MAXL.EQ.0) GO TO 4 *** 00001550
C *** SET UP COUPLING MODES, INDICES AND TEST FOR MODE 1 *** 00001560
C *** DO 5 L=1,MAXL *** 00001570
C *** I=ID(L,M) *** 00001580
C *** J=JD(L,M) *** 00001590
C *** IJ=I-1 *** 00001600
C *** JJ=J-1 *** 00001610
C *** IF (J.EQ.1) GO TO 42 *** 00001620
C *** COMPARE SUMS FOR SYMMETRIC DIFFERENCE COMBINATIONS *** 00001630
C *** SMF=SMF+TX(I)*PHIX(J)+TX(J)*PHIX(I)+PHIX(I)*TX(JJ) *** 00001640
C *** 1 SMS=SMS-TTH(I)*PHIT(J)+TTH(J)*PHIT(I)-PHIT(I)*TTH(JJ) *** 00001650
C *** 1 SMV=SMV-PHIT(I)*PHIT(J)+PHIT(J)*TX(T(I))+PHIT(I)*TX(T(J)) *** 00001660
C *** 1 SME=SME+PHIX(I)*TX(T(J))+PHIX(J)*TX(T(I))+PHIX(I)*TX(T(J)) *** 00001670
C *** 1 SMN=SMN+TX(I)*PHI(J)+TX(J)*PHI(I)*TX(JJ) *** 00001680
C *** 1 SMT=SMT+TTH(I)*PHI(J)+TTH(J)*PHI(I)+PHI(I)*TTH(JJ) *** 00001690
C *** 3 CONTINUE *** 00001700
C *** 2 MAXL=MAXD(M) *** 00001710
C *** TEST FOR PRESENCE OF SYMMETRIC DIFFERENCE COMBINATIONS *** 00001720
C *** IF (MAXL.EQ.0) GO TO 42 *** 00001730
C *** SET UP COUPLING MODES, INDICES AND TEST FOR MODE 1 *** 00001740
C *** DO 5 L=1,MAXL *** 00001750
C *** I=ID(L,M) *** 00001760
C *** J=JD(L,M) *** 00001770
C *** IJ=I-1 *** 00001780
C *** JJ=J-1 *** 00001790
C *** IF (J.EQ.1) GO TO 42 *** 00001800
C *** COMPARE SUMS FOR SYMMETRIC DIFFERENCE COMBINATIONS *** 00001810
C *** SMF=SMF+TX(I)*PHIX(J)+TX(J)*PHIX(I)+PHIX(I)*TX(JJ) *** 00001820
C *** 1 SMS=SMS-TTH(I)*PHIT(J)+TTH(J)*PHIT(I)-PHIT(I)*TTH(JJ) *** 00001830

```















```

132 MAXL=MAXD(MP)
IF (MAXL.EQ.0) GO TO 104
C**
C** SET UP COUPLING MODES! INDICES AND TEST FOR MODE 1
C**
DO 105 L=1,MAXL
I=ID(L,MP)
J=JD(L,MP)
II=I-1
JJ=J-1
IF (J.EQ.1) GO TO 123
C**
C** COMPILE SUMS FOR ASYMMETRIC DIFFERENCE COMBINATIONS
C**
SMF=SMF-PHIX(I)*TX(JJ)+PHIX(J)*TX(II)+PHIX(II)*TX(J)
- PHIX(JJ)*TX(I)
1 SMS=SMS+PHIT(I)*TTH(JJ)+PHIT(J)*TTH(II)+PHIT(II)*TTH(J)
+ PHIT(JJ)*TTH(I)
1 SMV=SMV+PHIT(I)*TXT(JJ)+PHIT(J)*TXT(II)+PHIT(II)*TXT(J)
+ PHIT(JJ)*TXT(I)
1 SME=SME+PHIX(I)*TXT(JJ)+PHIX(J)*TXT(II)+PHIX(II)*TXT(J)
+ PHIX(JJ)*TXT(I)
1 SMN=SMN+PHI(I)*TX(JJ)+PHI(J)*TX(II)+PHI(II)*TX(J)
+ PHI(JJ)*TX(I)
1 SMT=SMT+PHI(I)*TTH(JJ)+PHI(J)*TTH(II)+PHI(II)*TTH(J)
+ PHI(JJ)*TTH(I)
GO TO 105
C**
C** EXECUTE BELOW IF J=1 IN DIFF-COMB (OR I=1 IN SUM-COMB)
C**
123 SMF=SMF+(PHIX(I)*TX(II)+PHIX(II)*TX(I))*2.0
SMS=SMS+(PHIT(I)*TTH(II)+PHIT(II)*TTH(I))*2.0
SMV=SMV+(PHIT(I)*TXT(II)+PHIT(II)*TXT(I))*2.0
SME=SME+(PHIX(I)*TXT(II)+PHIX(II)*TXT(I))*2.0
SMN=SMN+(PHI(I)*TX(II)+PHI(II)*TX(I))*2.0
SMT=SMT+(PHI(I)*TTH(II)+PHI(II)*TTH(I))*2.0
105 CONTINUE
C**
C** TEXT FOR PRESENCE OF SAME-INDEX COMBINATION
C**
104 IF (MAXSY(MP).EQ.0) GO TO 10
C**
C** SET UP COUPLING MODES! INDICES AND COMPILE SUMS
C**
I=IJS(MP)
II=I-1
SMF=SMF+PHIX(I)*TX(II)+PHIX(II)*TX(I)
SMS=SMS-PHIT(I)*TTH(II)+PHIT(II)*TTH(I)
00002800
00002810
00002820
00002830
00002840
00002850
00002860
00002870
00002880
00002890
00002900
00002910
00002920
00002930
00002940
00002950
00002960
00002970
00002980
00002990
00003000
00003010
00003020
00003030
00003040
00003050
00003060
00003070
00003080
00003090
00003100
00003110
00003120
00003130
00003140
00003150
00003160
00003170
00003180
00003190
00003200
00003210
00003220
00003230
00003240
00003250
00003260
00003270

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C *** DO 60 M=1,MNMAXO 0001040
C *** KP=K+(M-1)*KMAX 0001050
C *** PHX(M)=PHIXB(KP) 0001060
C *** PHT(M)=PHTB(KP) 0001070
C *** DO 9 M=1,MNMAX 0001080
C *** SMO=0. 0001090
C *** SMT=0. 0001100
C *** SMR=0. 0001110
C *** SMF=0. 0001120
C *** TEST FOR ASYMMETRIC MODE 0001130
C *** IF (N(M).LT.0) GO TO 101 0001140
C *** 0001150
C *** 0001160
C *** 0001170
C *** 0001180
C *** 0001190
C *** THIS SECTION HANDLES SYMMETRIC MODE COMBINATIONS ONLY 0001200
C *** 0001210
C *** 0001220
C *** 0001230
C *** 0001240
C *** 0001250
C *** 0001260
C *** TEST FOR PRESENCE OF SYMMETRIC SUMMATION COMBINATIONS 0001270
C *** 0001280
C *** 0001290
C *** IF (MAXL.EQ.0) GO TO 2 0001300
C *** SET UP 'COUPLING' MODES, INDICES AND TEST FOR MODE 1 0001310
C *** DO 3 L=1,MAXL 0001320
C *** I=IS(L,M) 0001330
C *** J=JS(L,M) 0001340
C *** I=I-1 0001350
C *** JJ=J-1 0001360
C *** IF (I.EQ.1) GO TO 3 0001370
C *** 0001380
C *** 0001390
C *** 0001400
C *** COMPILE SUMS FOR SYMMETRIC SUMMATION COMBINATION MODES 0001410
C *** SMO=SMO+PHIX(I)*PHIX(J) 0001420
C *** 1 +PHX(I)*PHIX(J)+PHX(JJ)-PHIX(JJ)*PHX(JJ) 0001430
C *** 2 -PHIX(I)*PHIX(J) 0001440
C *** SMT=SMT-PHT(I)*PHT(J) 0001450
C *** 1 -PHT(I)*PHT(J)-PHT(J)*PHT(I) 0001460
C *** 2 +PHT(I)*PHT(J)+PHT(JJ)+PHT(JJ)*PHT(I) 0001470
C *** SMR=SMR+PHIX(I)*PHIX(J)+PHIX(J)*PHIX(I)+PHIX(JJ)*PHT(I) 0001480
C *** 1 +PHX(I)*PHT(I)+PHX(J)*PHT(J) 0001490
C *** 2 +PHIX(J)*PHT(I) 0001500
C *** 0001510

```







```

00002000
00002010
00002020
00002030
00002040
00002050
00002060
00002070
00002080
00002090
00002100
00002110
00002120
00002130
00002140
00002150
00002160
00002170
00002180
00002190
00002200
00002210
00002220
00002230
00002240
00002250
00002260
00002270
00002280
00002290
00002300
00002310
00002320
00002330
00002340
00002350
00002360
00002370
00002380
00002390
00002400
00002410
00002420
00002430
00002440
00002450
00002460
00002470

4 IF(MAXSY(M).EQ.0) GO TO 10
C **
C SET UP INDICES AND COMPILE SUMS
C **
I=IJS(M)
I=I-1
SMO=SMO+PHIX(I)**2/2.
+PHIX(I)**PHIX(I)
-PHIX(I)**2/2.0-PHIX(I)**PHX(I)
1 SMT=SMT-PHIT(I)**2/2.
-PHT(I)**PHIT(I)
+PHIT(I)**2/2.0+PHIT(I)**PHT(I)
2 SMR=(SMR+PHIX(I)**PHIT(I))
+PHX(I)**PHIT(I)+PHT(I)**PHIT(I)
1 +PHX(I)**PHIT(I)**PHIT(I)
2 SMF=SMF-PHIX(I)**2/2.
+PHI(I)**2/2.0
2 GO TO 10
C **
C THIS SECTION HANDLES CASES WHERE MODE 0 IS INCLUDED
C **
20 DO 21 L=1,MNMAXO
SMO=SMO+PHIX(L)**2
+2.0*PHX(L)**PHIX(L)
1 SMT=SMT+PHIT(L)**2
+2.0*PHT(L)**PHIT(L)
21 SMF=SMF+PHIX(M)**2
SMO=SMO+PHIX(M)**2
+2.0*PHX(M)**PHIX(M)
1 SMF=SMF+PHI(L)**2
SMT=SMT+PHIT(L)**(PHIT(L)+2.0*PHT(L))
SMR=SMR+(PHIX(L)**(PHIT(L)+PHX(L))*PHIT(L+1)
DO 122 L=2,MNMAXO,2
SMR=SMR+PHIX(L)**(PHIT(L+1)+PHT(L+1))*PHIT(L+1)
DO 121 L=3,MNMAXO,2
SMR=SMR+PHIX(L)**(PHIT(L-1)+PHX(L))*PHIT(L-1)
121 SMR=SMR+PHIX(L)**(PHIT(L-1)+PHX(L))*PHIT(L-1)
C **
C COMPILE BETA TERMS FOR THIS SPECIAL CASE
C **
BX3(M)=SMO*.5
BT3(M)=SMT*.5
BE3(M)=SMF*.5
BXT3(1)=SMR*.5
GO TO 9
C **
C THIS SECTION HANDLES ASYMMETRIC MODES
C **

```





```

C ** 101 MP=M+1 ** 00002480
C ** MAXL=MAXS(MP) ** 00002490
C ** ** 00002500
C ** TEST FOR PRESENCE OF SUMMATION COMBINATIONS ** 00002510
C ** ** 00002520
C ** IF (MAXL.EQ.0) GO TO 102 ** 00002530
C ** ** 00002540
C ** SET UP INDICES FOR SUMMATION COMBINATIONS ** 00002550
C ** ** 00002560
C ** DO 103 L=1,MAXL ** 00002570
C ** I=IS(L,MP) ** 00002580
C ** J=JS(L,MP) ** 00002590
C ** II=I-1 ** 00002600
C ** JJ=J-1 ** 00002610
C ** ** 00002620
C ** ** 00002630
C ** TEST FOR MODE 1 AND COMPILE SUMS ** 00002640
C ** ** 00002650
C ** IF (I.EQ.1) GO TO 103 ** 00002660
C ** SMO=SMO+PHX(I)*(PHX(JJ)+PHX(JJ))*(PHX(II)+ ** 00002670
C ** PHX(II))+PHX(II)*(PHX(JJ)+PHX(JJ))*(PHX(II)+ ** 00002680
C ** SMT=SMT+PHIT(II)*(PHIT(JJ)+PHIT(JJ))*(PHIT(II)+ ** 00002690
C ** PHIT(II))+PHIT(II)*(PHIT(JJ)+PHIT(JJ))*(PHIT(II)+ ** 00002700
C ** SMR=SMR+PHX(II)*(PHIT(JJ)+PHIT(JJ))+PHX(II)+ ** 00002710
C ** PHIT(II))-PHX(II)*(PHIT(JJ)+PHIT(JJ))-PHX(II)* ** 00002720
C ** (PHIT(II)+PHIT(II))+PHX(II)*PHIT(JJ)+PHX(II)- ** 00002730
C ** PHX(II)*PHIT(JJ)-PHX(JJ)*PHIT(II) ** 00002740
C ** SMF=SMF+PHI(I)*PHI(JJ)+PHI(J)*PHI(II) ** 00002750
C ** 103 CONTINUE ** 00002760
C ** ** 00002770
C ** TEST FOR PRESENCE OF DIFFERENCE COMBINATIONS ** 00002780
C ** ** 00002790
C ** 102 MAXL=MAXD(MP) ** 00002800
C ** IF (MAXL.EQ.0) GO TO 104 ** 00002810
C ** ** 00002820
C ** SET UP INDICES FOR DIFFERENCE COMBINATIONS ** 00002830
C ** ** 00002840
C ** DO 105 L=1,MAXL ** 00002850
C ** I=ID(L,MP) ** 00002860
C ** J=JD(L,MP) ** 00002870
C ** II=I-1 ** 00002880
C ** JJ=J-1 ** 00002890
C ** ** 00002900
C ** TEST FOR MODE 1 AND COMPILE SUMS ** 00002910
C ** ** 00002920
C ** IF (J.EQ.1) GO TO 123 ** 00002930
C ** SMO=SMO-PHX(II)*(PHX(JJ)+PHX(JJ))*(PHX(II)+ ** 00002940
C ** 1 PHX(II))+PHX(II)*PHX(JJ)-PHX(JJ)*PHX(II) ** 00002950

```





```

SMT=SMT+PHIT(I)*(PHIT(JJ)+PHT(JJ))-PHIT(JJ)*(PHIT(II)+
1 PHT(II))-PHIT(II)*(PHT(JJ)+PHIT(JJ)*PHT(I)
SMT=SMR+PHIX(I)*(PHIT(JJ)+PHT(JJ))+PHIX(JJ)*(PHIT(II)+
1 PHT(II))+PHIX(II)*(PHT(JJ)+PHT(JJ)+PHIX(JJ)*
2 (PHIT(II)+PHT(II))+PHIX(I)*PHIT(JJ)+PHIX(J)*PHIT(II)+
3 PHX(II)*PHIT(JJ)+PHX(JJ)*PHIT(I)
SMF=SMF+PHI(I)*PHI(JJ)-PHI(JJ)*PHI(II)
GO TO 105
C ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **
C ** ** ** * IN DIFFERENCE COMBINATIONS
C ** ** ** *
123 SMO=SMO+(PHIX(I)*(PHIX(II)+PHX(II))+PHIX(II)*PHX(I))*2.0
SMT=SMT+(PHIT(I)*(PHIT(II)+PHT(II))+PHIT(I)*PHT(II))*2.0
SMR=SMR+(PHIX(I)*(PHIT(II)+PHT(II))+PHIX(II)*(PHIT(I)+
1 PHT(I))+PHX(I)*PHIT(II)+PHX(II)*PHIT(I))*2.0
SMF=SMF+(PHI(I)*PHI(II))*2.0
105 CONTINUE
C ** ** ** *
C ** ** ** * TEST FOR PRESENCE OF SAME-INDEX COMBINATION
C ** ** ** *
104 IF (MAXSY(MP).EQ.0) GO TO 10
C ** ** ** *
C ** ** ** * SET UP INDICES AND COMPILE SUMS
C ** ** ** *
I=IJS(MP)
II=I-1
SMO=SMO+PHIX(I)*(PHIX(II)+PHX(II))+PHIX(II)*PHX(I)
SMT=SMT+PHIT(I)*(PHIT(II)+PHT(II))+PHIT(II)*PHT(I)
SMR=SMR+PHIX(I)*(PHIT(II)+PHT(II))-PHIX(II)*(PHIT(I)+
1 PHT(I))+PHX(I)*PHIT(II)-PHX(II)*PHIT(I)
SMF=SMF+PHI(I)*PHI(II)
C ** ** ** *
C ** ** ** * COMPILE BETA TERMS
C ** ** ** *
10 BX3(M)=SMO
BT3(M)=SMT
BXT3(M)=SMR*.5
BE3(M)=SMF
9 CONTINUE
222 RETURN
END
00002960
00002970
00002980
00002990
00003000
00003010
00003020
00003030
00003040
00003050
00003060
00003070
00003080
00003090
00003100
00003110
00003120
00003130
00003140
00003150
00003160
00003170
00003180
00003190
00003200
00003210
00003220
00003230
00003240
00003250
00003260
00003270
00003280
00003290
00003300
00003310
00003320
00003330
00003340
00003350
00003360
00003370

```



```

SUBROUTINE MODES
  IN THIS SUBROUTINE, ARRAYS THAT DEFINE THOSE SETS OF INDICES
  THAT COMBINE TO EQUAL EACH VALUE OF N IN THE PROBLEM ARE DETER-
  MINED. MODES IS CALLED PRIOR TO THE FIRST ITERATION AND AFTER
  EVERY ITERATION UNTIL A SPECIFIED NUMBER OF FOURIER TERMS IS
  REACHED. EACH FOURIER INDEX IN THE RESULT IS SUBTRACTED FROM
  ALL OTHER FOURIER INDICES AND THE NEW VALUE EXISTS IN THE PROGRAM.
  FOURIER INDICES TO SEE IF THE TWO INDICES THAT MADE THE COM-
  BINATION ARGUMENT OF EACH ARRAY IS THE VALUE OF THE NEW INDEX, ID AND
  JD. ONE OTHER IS THE NUMBER OF COMBINATIONS OF INDICES THAT INDEX
  AND THE OTHER IS THE VALUE OF THE INDEX. IF THERE IS NO INDEX IN THE
  PROGRAM THAT MATCHES THE NEW ONE, THEN A NEW FOURIER TERM HAS
  BEEN GENERATED AND WILL BE CONSIDERED IN THE NEXT ITERATION FOR
  SOLUTION. THE VARIABLE MAXD STORES THE TOTAL NUMBER OF SUCH
  COMBINATIONS FOR EACH VALUE OF THE FOURIER INDEX.
  IN A SIMILAR MANNER, EACH INDEX IS ADDED TO EVERY OTHER
  INDEX AND THE SUM COMPARED WITH ALL INDICES. THIS RESULT IS
  STORED IN THE 2-DIMENSIONAL ARRAYS 'IS' AND 'JS', IN THE SAME
  MANNER AS WAS DONE FOR THE SUBTRACTION CASE. THE VARIABLE
  'MAXS' STORES THE TOTAL NUMBER OF SUMMATION COMBINATIONS FOR
  EACH VALUE OF THE FOURIER INDEX.
  A SPECIAL ROUTINE HANDLES THE CASE WHERE THE INDEX IS ADD-
  ED TO ITSELF, THE SUM COMPARED WITH ALL OTHER INDICES. THE 1-
  DIMENSIONAL ARRAY 'IJS' STORES THE LOCATION OF THE INDEX AND
  THE VARIABLE 'MAXSY' INDICATES IF THIS COMBINATION EXISTS.
  SINCE THE INDEX SUBTRACTS FROM ITSELF, ALWAYS GIVES MODE '0',
  NO SPECIFIC STATEMENTS ARE REQUIRED IN THAT CASE.
  WITH THIS PROCEDURE, THE SERIES OF PRODUCTS THAT MAKE UP
  THE BETA'S AND ALPHA'S CONTAIN NO ZERO TERM, AND THE SUMMATION
  IS CARRIED OUT IN PHIBET(K) AND TEAETA(K) OVER SPECIFICALLY
  DEFINED LIMITS.
  THE VARIOUS 'JUMP' IS '1' UNLESS SPECIFICALLY SET TO '2',
  ON INPUT CARDS, INDICATING PROCESSING OF GENERAL ASYMMETRIC
  LOADS AND IMPERFECTIONS. IN SATANS-I, THE NUMBER OF MODES IS
  LIMITED TO 25.
  COMMON /IBL1/ MNMAX
  COMMON /IBL2/ N(25), MNINIT

```









```

C ** DO WE WANT ANY MORE NEW MODES ** 00000900
C ** IF(ICORFL.EQ.1) GO TO 1 ** 00000910
C ** ** 00000920
C ** FROM HERE TO 1, WE INCREMENT COUNTERS AND MAKE APPROPRIATE ** 00000930
C ** ENTRIES IN 'MAXD','ID','JD' TO SIMPLIFY USAGE OF 'ID' ** 00000940
C ** AND 'JD' IN TEAETA AND PHIBET. MODES ARE PLACED IN THESE ** 00000950
C ** ARRAYS SUCH THAT THE HIGHER MODE NUMBER IS ALWAYS FIRST ** 00000960
C ** ** 00000970
C ** MNMAX=MNMAX+JUMP ** 00000980
C ** ** 00000990
C ** N(MNMAX)=NTEST ** 0001000
C ** IF (JUMP.GT.1) N(MNMAX-1)=-NTEST ** 0001010
C ** MMFT=MNMAX ** 0001020
C ** IF(MNMAX.EQ.MAXM) ICORFL=1 ** 0001030
C ** IF(NMN-NMM) 11,1,12 ** 0001040
C ** 10 LOC=MAXD(MMFT)+1 ** 0001050
C ** 11 MAXD(MMFT)=LOC ** 0001060
C ** ID(LOC,MMFT)=MM ** 0001070
C ** JD(LOC,MMFT)=MN ** 0001080
C ** GO TO 1 ** 0001090
C ** 12 LOC=MAXD(MMFT)+1 ** 0001100
C ** MAXD(MMFT)=LOC ** 0001110
C ** ID(LOC,MMFT)=MN ** 0001120
C ** JD(LOC,MMFT)=MM ** 0001130
C ** 1 CONTINUE ** 0001140
C ** ** 0001150
C ** ** 0001160
C ** ** 0001170
C ** ** 0001180
C ** ** 0001190
C ** ** 0001200
C ** ** 0001210
C ** ** 0001220
C ** ** 0001230
C ** ** 0001240
C ** ** 0001250
C ** ** 0001260
C ** ** 0001270
C ** ** 0001280
C ** ** 0001290
C ** ** 0001300
C ** ** 0001310
C ** ** 0001320
C ** ** 0001330
C ** ** 0001340
C ** ** 0001350
C ** ** 0001360
C ** ** 0001370

THIS SECTION HANDLES MODES GENERATED FROM THE SUMMATION
COMBINATIONS OF EXISTING MODES

NOW SET UP INITIAL LOOP FOR SUM COMBINATIONS
DO 301 MN=1,MNMAXO,JUMP
NMN=N(MN)
NNS=MN
IF(MNINIT.GT.MN) NNS=MNINIT
SET UP SECOND LOOP - TO ADD PRESENT MODE TO ALL OTHER MODES
DO 301 MM=NNS,MNMAXO,JUMP
AMM=N(MM)
CREATE SUM
NTEST=NMN+MM

```









00001860  
00001870  
00001880  
00001890

```
IF(ICORFL.GT.0) IPASS=IPASS+1
IF(IPASS.LT.2.AND.MNINIT.LE.MNMAX) CALL PMATRIX
RETURN
END
```

```

SUBROUTINE INLPOL
C*****
C      THIS SUBROUTINE COMPUTES THE NON-LINEAR TERMS BETA-SUB S,
C      -SUB THETA, -SUB S-THETA, AETA-SUB S-S AND -SUB THETA-S AT AN
C      INITIAL POLE.
C*****
COMMON /IBL1/ MNMAX
COMMON /IBL3/ M0,M1,M2,M3
COMMON /IBL11/ ICORFL,IPASS,JUMP,MPERFS
COMMON /IBL12/ KMAX1,KMAX2,NCONV
COMMON /IBL13/ ITRMAX,LSMAX
COMMON /BL5/ TT(25),EMT(25),DT(25),DMT(25)
COMMON /BL6/ Z(4,1001),SOE,OSE,ALOAD
COMMON /BL7/ D1,S1
COMMON /BL11/ OMXI(100),PHEE,TO,T2
COMMON /BL11A/ PHEN,T2N
COMMON /BL17/ DEL
COMMON /BL29/ BX1(25),BT1(25),BX2(25),BT2(25),
1          BX12(25),BE2(25)
COMMON /BL30/ EXX1(25),ET1(25),EX1(25),ET1(25),EXX2(25),
1          ET2(25),ETX2(25),EX2(25),ET2(25)
COMMON /BL31/ DELSQ,EX1(25)
C*****
IF (JUMP.EQ.2) GO TO 1000
DO 1 MN=1,MNMAX
  BX1(MN)=0.
  BT1(MN)=0.
  BX11(MN)=0.
  BE1(MN)=0.
  EX1(MN)=0.
  ET1(MN)=0.
  ETX1(MN)=0.
C*****
00000010
00000020
00000030
00000040
00000050
00000060
00000070
00000080
00000090
00000100
00000110
00000120
00000130
00000140
00000150
00000160
00000170
00000180
00000190
00000200
00000210
00000220
00000230
00000240
00000250
00000260
00000270
00000280
00000290
00000300
00000310
00000320

```



```

1 EXX1(MN)=0.
  IF(M1.EQ.0) RETURN
  I2=2+(M1-1)*KMAX2
  I3=I2+1
  I4=I3+1
  PHEE=(1.5*Z(3,I2)-2.*Z(3,I3)+.5*Z(3,I4))/DEL+OMXI(1)*Z(1,I2)
  BET=.5*PHEE**2
  IF(IIRMAX.EQ.1) BET=0.
  T2=0.
  IF(M2.EQ.0) GO TO 2
  CALL BDB(1,B,DB,D,DD)
  I2=2+(M2-1)*KMAX2
  I3=I2+1
  I4=I3+1
  T2=B*DI*((-1.5*Z(1,I2)+2.*Z(1,I3)-.5*Z(1,I4))/DEL+.5*SOE*BET)
  Q1=.5*PHEE*T2
  BX1(M2)=BET
  BT1(M2)=-BET
  BXT1(M2)=-BET
  ETX1(M1)=Q1
  IF(M3.EQ.0) GO TO 2
  EXX1(M3)=Q1
  ETX1(M3)=-Q1
  T2=0.
  IF(M0.EQ.0) GO TO 3
  BX1(M0)=BET
  BT1(M0)=BET
  CALL BDB(1,B,DB,D,DD)
  CALL TLOAD(1)
  I2=2+(M0-1)*KMAX2
  I3=I2+1
  I4=I3+1
  T2=B*SI*((-1.5*Z(1,I2)+2.*Z(1,I3)-.5*Z(1,I4))/DEL+OMXI(1)*Z(3,I2)
  1+.5*SOE*BET)-TT(M0)*ALOAD
3 EXX1(M1)=PHEE*(T2+.5*T2)
  RETURN
1000 DO 1001 MN=1,MNMAX
      BX1(MN)=0.
      BT1(MN)=0.
      BXT1(MN)=0.
      BE1(MN)=0.
      EX1(MN)=0.
      ET1(MN)=0.
      ETX1(MN)=0.
      EXX1(MN)=0.
      IF(M1.EQ.0) RETURN
      I2=2+(M1-1)*KMAX2
      I3=I2+1

```





```

I4=I3+1
PHEE=(1.5*Z(3,I2)-2.*Z(3,I3)+.5*Z(3,I4))/DEL+OMXI(1)*Z(1,I2)
T2=0.
IF(M2.EQ.0) GO TO 1002
CALL BDB(1,B,DB,D,DD)
I2=2+(M2-1)*KMAX2
I3=I2+1
I4=I3+1
PHX1=PHIXB(KMAX+1)
PHX2=PHIXB(2*<MAX+1)
PHEN=(1.5*Z(3,I2-KMAX2)-2.*Z(3,I3-KMAX2)+.5*Z(3,I4-KMAX2))/DEL+
1 OMXI(1)*Z(1,I2-KMAX2)
BX1(M2)=.5*(PHEE*(PHEE+2.*PHX1)-PHEN*(PHEN+2.*PHX2))
IF(ITRMAX.EQ.1) BX1(M2)=0.
BT1(M2)=-BX1(M2)
BX1(M2)=-BX1(M2)
T2=B*D1*((-1.5*Z(1,I2)+2.*Z(1,I3)-.5*Z(1,I4))/DEL+.5*SOE*BX1(M2))
M2L=M2-1
BX1(M2L)=PHEE*(PHEN+PHX2)+PHX1*PHEN
IF(ITRMAX.EQ.1) BX1(M2L)=0.
BT1(M2L)=-BX1(M2L)
BX1(M2L)=BX1(M2L)
T2N=B*D1*((-1.5*Z(1,I2-KMAX2)+2.*Z(1,I3-KMAX2)-.5*Z(1,I4-KMAX2))
1 /DEL+.5*SOE*BX1(M2L))
1002 T2=0.
IF(M2.EQ.0) GO TO 1003
BX1(M2)=.5*(PHEE*(PHEE+2.*PHX1)+PHEN*(PHEN+2.*PHX2))
IF(ITRMAX.EQ.1) BX1(M2)=0.
BT1(M2)=BX1(M2)
CALL BDB(1,B,DB,D,DD)
CALL TLOAD(1)
I2=2+(M2-1)*KMAX2
I3=I2+1
I4=I3+1
T2=B*D1*((-1.5*Z(1,I2)+2.*Z(1,I3)-.5*Z(1,I4))/DEL+OMXI(1)*Z(3,I2)
1 +.5*SOE*BX1(M2))-T1(M2)*ALOAD
1003 IF(ITRMAX.EQ.1) RETURN
PHSS=PHEE+PHX1
PHSP=PHEN+PHX2
M1L=M1-1
EXX1(M1)=PHSS*T2+.5*(PHSS*T2+PHSP*T2N)
EXX1(M1L)=PHSP*T2-.5*(PHSP*T2-PHSS*T2N)
ETX1(M1)=.5*(PHSS*T2+PHSP*T2N)
ETX1(M1L)=-.5*(PHSP*T2-PHSS*T2N)
IF(M3.EQ.0) RETURN
M3L=M3-1
EXX1(M3)=.5*(PHSS*T2-PHSP*T2N)
EXX1(M3L)=-.5*(PHSS*T2N+PHSP*T2)

```





00001290  
00001300  
00001310  
00001320

```
ETX1(M3)=.5*(-PHSS*T2+PHSP*T2)
ETX1(M3L)=.5*(-PHSP*T2-PHSS*T2N)
RETURN
END
```

```

SUBROUTINE FNLPOL
C*****
C THIS SUBROUTINE COMPUTES THE NON-LINEAR TERMS BETA-S,
C -SUB THETA, -SUB S-THETA, AETA-S-S, AND -SUB THETA-S AT A
C FINAL POLE.
C*****
COMMON /IBL1/ MNMAX
COMMON /IBL3/ M3,M1,M2,M3
COMMON /IBL4/ KMAX,KL
COMMON /IBL11/ ICORFL,IPASS,JUMP,MPEFS
COMMON /IBL12/ KMAX1,KMAX2,NCONV
COMMON /IBL13/ ITRMAX,LSMAX
COMMON /BL5/ TT(25),EMT(25),DT(25),DMT(25)
COMMON /BL6/ Z(4,1001),SOE,OSE,ALOAD
COMMON /BL7/ D1,S1
COMMON /BL11A/ PHEN,T2N
COMMON /BL11/ OMXI(100),PHEE,TO,T2
COMMON /BL17/ DEL
COMMON /BL28/ BX3(25),BT3(25),BXI3(25),BE3(25)
COMMON /BL28/ EXX3(25),ETI3(25),ETX3(25),EXT3(25),EX3(25),ET3(25)
C*****
C IF (JUMP.EQ.2) GO TO 1000
DO 1 MN=1,MNMAX
BX3 (MN)=0.
BT3 (MN)=0.
BXI3 (MN)=0.
BE3 (MN)=0.
EX3 (MN)=0.
ET3 (MN)=0.
ETX3 (MN)=0.
EXX3 (MN)=0.
1 CALL BDB(KMAX,B,DB,D,DB)
C*****
00000010
00000020
00000030
00000040
00000050
00000060
00000070
00000080
00000090
00000100
00000110
00000120
00000130
00000140
00000150
00000160
00000170
00000180
00000190
00000200
00000210
00000220
00000230
00000240
00000250
00000260
00000270
00000280
00000290
00000300
00000310
00000320

```



```

IF(M1.EQ.0) RETURN
KM=KMAX1+(M1-1)*KMAX2
KM1=KM-1
KM2=KM-2
PHEE=-(1.5*Z(3,KM)-2.*Z(3,KM1)+.5*Z(3,KM2))/DEL+OMXI(KMAX)*Z(1,KM)
BET=.5*PHEE*2
IF(ITRMAX.EQ.1) BET=0.
T2=0.
IF(M2.EQ.0) GO TO 2
KM=KMAX1+(M2-1)*KMAX2
KM1=KM-1
KM2=KM-2
T2=B*D1*((1.5*Z(1,KM)-2.*Z(1,KM1)+.5*Z(1,KM2))/DEL+.5*SOE*BET)
Q1=.5*PHEE*T2
BX3(M2)=BET
BXT3(M2)=-BET
BXT3(M1)=Q1
ETX3(M1)=Q1
IF(M3.EQ.0) GO TO 2
EXX3(M3)=Q1
ETX3(M3)=-Q1
TJ=J.
2 IF(M0.EQ.0) GO TO 3
CALL TLOAD(KMAX)
KM=KMAX1+(M0-1)*KMAX2
KM1=KM-1
KM2=KM-2
BX3(M0)=BET
BT3(M0)=BET
T0=B*S1*((1.5*Z(1,KM)-2.*Z(1,KM1)+.5*Z(1,KM2))/DEL+OMXI(KMAX)*
1 Z(3,KM)+.5*SOE*BET)-TT(M0)*ALOAD
3 EXX3(M1)=PHEE*(T0+.5*T2)
RETURN
1000 DO 1001 MN=1,MNMAX
BX3(MN)=0.
BT3(MN)=0.
BXT3(MN)=0.
BE3(MN)=0.
EX3(MN)=0.
ET3(MN)=0.
ETX3(MN)=0.
EXX3(MN)=0.
CALL BDB(KMAX,B,DB,D,DB)
IF(M1.EQ.0) RETURN
KM=KMAX1+(M1-1)*KMAX2
KM1=KM-1
KM2=KM-2
PHEE=-(1.5*Z(3,KM)-2.*Z(3,KM1)+.5*Z(3,KM2))/DEL+OMXI(KMAX)*Z(1,KM)

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T2=0.
IF(M2.EQ.0) GO TO 1002
KM=KMAX1+(M2-1)*KMAX2
KM1=KM-1
KM2=KM-2
J=KMAX*2
I=J+KMAX
PHX1=PHI*XB(J)
PHX2=PHI*XB(I)
PHEN=-(1.5*Z(3,KM-KMAX2)-2.*Z(3,KM1-KMAX2)+.5*Z(3,KM2-KMAX2))/DEL
1+OMXI(KMAX)*Z(1,KM-KMAX2)
BX3(M2)=.5*(PHEE*(PHEE+2.*PHX1)-PHEN*(PHEN+2.*PHX2))
IF(ITRMAX.EQ.1) BX3(M2)=0.
BT3(M2)=-BX3(M2)
BXT3(M2)=BX3(M2)
M2L=M2-1
BX3(M2L)=PHEE*(PHEN+PHX2)+PHX1*PHEN
IF(ITRMAX.EQ.1) BX3(M2L)=0.
BT3(M2L)=-BX3(M2L)
BXT3(M2L)=-BX3(M2L)
T2=B*D1*((1.5*Z(1,KM)-2.*Z(1,KM1)+.5*Z(1,KM2))/DEL+.5*SOE*B*BX3(M2))
T2N=B*D1*((1.5*Z(1,KM-KMAX2)-2.*Z(1,KM1-KMAX2)+.5*Z(1,KM2-KMAX2))
1 /DEL+.5*SOE*B*BX3(M2L))
1002 TO=0.
IF(MJ.EQ.0) GO TO 1003
CALL TLOAD(KMAX)
KM=KMAX1+(M0-1)*KMAX2
KM1=KM-1
KM2=KM-2
BX3(M0)=.5*(PHEE*(PHEE+2.*PHX1)+PHEN*(PHEN+2.*PHX2))
IF(ITRMAX.EQ.1) BX3(M0)=0.
BT3(M0)=BX3(M0)
TJ=B*S1*((1.5*Z(1,KM)-2.*Z(1,KM1)+.5*Z(1,KM2))/DEL+OMXI(KMAX)*
1 Z(3,KM)+.5*SOE*B*BX3(M0))-TT(M0)*ALOAD
1003 IF(ITRMAX.EQ.1) RETURN
PHSS=PHEE+PHX1
PHSP=PHEN+PHX2
M1L=M1-1
EXX3(M1)=PHSS*TO+.5*(PHSS*T2+PHSP*T2N)
EXX3(M1L)=PHSP*TO-.5*(PHSP*T2-PHSS*T2N)
ETX3(M1)=.5*(PHSS*T2+PHSP*T2N)
ETX3(M1L)=.5*(-PHSP*T2+PHSS*T2N)
1 IF(M3.EQ.0) RETURN
M3L=M3-1
EXX3(M3)=.5*(PHSS*T2-PHSP*T2N)
EXX3(M3L)=.5*(PHSS*T2N+PHSP*T2)
ETX3(M3)=.5*(-PHSS*T2+PHSP*T2N)
ETX3(M3L)=.5*(-PHSP*T2-PHSS*T2N)
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RETURN  
END

00001290  
00001300

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C** SUBROUTINE POLE(K)
C** THIS SUBROUTINE PRINTS THE SOLUTION AT AN INITIAL AND A FINAL
C** POLE.
C** IMPLICIT LOGICAL*1 ($)
REAL NU,MT,MX,MTH,MXT,MTS,KX,KT,KXT,LAM,LAM2,MASS
COMMON /IBL2/ N(25),MNINIT
COMMON /IBL3/ MO,M1,M2,M3
COMMON /IBL4/ KMAX,KL
COMMON /IBL5/ IBCFNL
COMMON /IBL7/ MNMAXO,MAXD(25),MAXS(25),MAXSY(25),IS(25,25),
1 JS(25,25),ID(25,25),JD(25,25),IJS(25)
COMMON /IBL8/ LSTEP,ITR
COMMON /IBL10/ IFREQ,NTHMAX
COMMON /IBL11/ ICORFL,IPASS,JUMP,MPERFS
COMMON /IBL12/ KMAX1,KMAX2,NCONV
COMMON /BL4/ P(4,4,951),X(4,951),ZF1M(4,4,25),ZF2M(4,4,25),
1 ZF3M(4,4,25),ZF4M(4,4,25)
COMMON /BL5/ TT(25),MT(25),DT(25),DMT(25)
COMMON /BL6/ Z(4,100),SOE,OSE,ALOAD
COMMON /BL7/ DI,SI
COMMON /BL8/ R(100),GAM(100),OMT(100)
COMMON /BL9/ PHIX(25),PHIT(25),PHI(25)
COMMON /BL11/ OMXI(100),PHEE,T0,T2
COMMON /BL11A/ PHEN,T2N
COMMON /BL12/ TDLI,TDEL
COMMON /BL14/ LAM2,LSD18,LSD1N
COMMON /BL15/ NU,U1(25),V1(25),W1(25),V2(25),U2(25),W2(25),U3(25),
1 V3(25),W3(25)
COMMON /BL17/ DEL
COMMON /BL19/ TH(36)
COMMON /BL20/ DEOMX(100)
COMMON /BL27/ BX3(25),BT3(25),BXT3(25),BE3(25)
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COMMON /BL31/ DELSQ,EXT1(25)
COMMON /BL32/ TKN,ELAST,CHAR,SIGO
COMMON /BL100/ TEEQ,$DYNMC
COMMON /BL101/ ZO(4,1001),Z2(4,1001),Z3(4,1001),DELSO
COMMON /BL102/ DELOAD
COMMON /BL103/ MASS(100)
COMMON /BL110/ TX(25),TTH(25),MX(25),MTH(25),MXT(25),
1
COMMON /BL111/ ABZ,ABZO,ABZN,ABZ3,DD2
C*****
IF (JUMP.EQ.2) GO TO 1000
CALL BDB(K,BS,DB,DS,DD)
IF(K.EQ.KMAX) GO TO 301
DO 202 MN=1,MNMAXO
U1(MN)=U2(MN)
V1(MN)=V2(MN)
W1(MN)=W2(MN)
I3=3+(MN-1)*KMAX2
I2=I3-1
U2(MN)=Z(1,I3)
V2(MN)=Z(2,I3)
W2(MN)=Z(3,I3)
PHIX(MN)=0.0
PHIT(MN)=0.0
PHI(MN)=0.0
MX(MN)=Z(4,I2)*ABZ3
MTH(MN)=0.0
MXT(MN)=0.0
QS(MN)=0.0
TX(MN)=0.0
TTH(MN)=0.0
TXT(MN)=0.0
IF(M1.EQ.0) GO TO 203
CALL INLPOL
PHIX(M1)=PHEE*ABZO
PHIT(M1)=-PHEE*ABZO
QS(M1)=0.0
IF(MJ.EQ.0) GO TO 204
TX(MO)=TO*ABZ
TTH(MO)=TO*ABZ
MTH(MJ)=MX(MJ)
IF(M2.EQ.0) GO TO 205
TX(M2)=T2*ABZ
TTH(M2)=-T2*ABZ
TXT(M2)=-T2*ABZ
MTH(M2)=-MX(M2)
MXT(M2)=MTH(M2)
GO TO 205
202
IF(M1.EQ.0) GO TO 203
CALL INLPOL
PHIX(M1)=PHEE*ABZO
PHIT(M1)=-PHEE*ABZO
QS(M1)=0.0
IF(MJ.EQ.0) GO TO 204
TX(MO)=TO*ABZ
TTH(MO)=TO*ABZ
MTH(MJ)=MX(MJ)
IF(M2.EQ.0) GO TO 205
TX(M2)=T2*ABZ
TTH(M2)=-T2*ABZ
TXT(M2)=-T2*ABZ
MTH(M2)=-MX(M2)
MXT(M2)=MTH(M2)
GO TO 205
204
IF(M1.EQ.0) GO TO 203
CALL INLPOL
PHIX(M1)=PHEE*ABZO
PHIT(M1)=-PHEE*ABZO
QS(M1)=0.0
IF(MJ.EQ.0) GO TO 204
TX(MO)=TO*ABZ
TTH(MO)=TO*ABZ
MTH(MJ)=MX(MJ)
IF(M2.EQ.0) GO TO 205
TX(M2)=T2*ABZ
TTH(M2)=-T2*ABZ
TXT(M2)=-T2*ABZ
MTH(M2)=-MX(M2)
MXT(M2)=MTH(M2)
GO TO 205

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203 IF(MO.EQ.0) GO TO 206
    I3=3+(M3-1)*KMAX2
    I4=I3+1
    CALL TLOAD(1)
    TX(M3)=BS*SI*((2.*Z(1,I3)-.5*Z(1,I4))/DEL+OMXI(1)*Z(3,I3-1))*ABZ
1   TT(M3)=TX(M3)
    MTH(M3)=MX(M3)
206 IF(M2.EQ.0) GO TO 205
    I3=3+(M2-1)*KMAX2
    I4=I3+1
    TX(M2)=BS*D1*((2.*Z(1,I3)-.5*Z(1,I4))/DEL
    TX(M2) = TX(M2)*ABZ
    TTH(M2) = -TX(M2)
    TXT(M2) = -TX(M2)
    MTH(M2) = -MX(M2)
    MXT(M2) = -MX(M2)
205 RETURN
301 CONTINUE
    DO 302 MN=1,MNMAX0
    U1(MN)=U2(MN)
    V1(MN)=V2(MN)
    W1(MN)=W2(MN)
    PHIX(MN)=0.
    PHIT(MN)=0.
    PHI(MN)=0.
    IK=KMAX1+(MN-1)*KMAX2
    MX(MN)=Z(4,IK)*ABZ3
    MTH(MN)=0.
    MXT(MN)=0.
    TX(MN)=0.
    TTH(MN)=0.
    TTT(MN)=0.
302 IF(M1.EQ.0) GO TO 303
    CALL FNLPOL
    PHIX(M1)=PHEE*ABZ0
    PHIT(M1)=PHEE*ABZ0
    QS(M1)=0.
    IF(M0.EQ.0) GO TO 304
    TX(M0)=TJ*ABZ
    TTH(M0)=T0*ABZ
    MTH(M0)=MX(M0)
304 IF(M2.EQ.0) GO TO 305
    TX(M2)=T2*ABZ
    TTH(M2)=-T2*ABZ
    TXT(M2)=T2*ABZ
    MTH(M2)=-MX(M2)

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303      MXT(M2) =MX(M2)
      GO TO 305
      IF(MO.EQ.0) GO TO 306
      IKM=KMAX+(MO-1)*KMAX2
      IM1=IKM-1
      CALL TLOAD(KMAX)
      TX(MO)=BS*SI*((-2.*Z(1,IKM)+.5*Z(1,IM1))/DEL+OMXI(KMAX)*Z(3,IKM+1)
1      )*ABZ-TT(MO)*ABZ*ALOAD
      TTH(MO) =TX(MO)
      MTH(MO) =MX(MO)
      IF(M2.EQ.0) GO TO 305
306      IKM=KMAX+(M2-1)*KMAX2
      IM1=IKM-1
      TX(M2)=BS*DI*(-2.*Z(1,IKM)+.5*Z(1,IM1))/DEL
      TX(M2)=TX(M2)*ABZ
      TTH(M2) =-TX(M2)
      TTX(M2) =TX(M2)
      MTH(M2) =-MX(M2)
      MXT(M2) =MX(M2)
305      RETURN
1000     CALL BDB(K,BS,DB,DS,DD)
      IF(K.EQ.KMAX) GO TO 1301
      DO 1202 MN=1,MNMAXO
      U1(MN)=U2(MN)
      V1(MN)=V2(MN)
      W1(MN)=W2(MN)
      I3=3+(MN-1)*KMAX2
      I2=I3-1
      U2(MN)=Z(1,I3)
      V2(MN)=Z(2,I3)
      W2(MN)=Z(3,I3)
      PHIX(MN)=0.
      PHIT(MN)=0.0
      PHI(MN)=0.
      MX(MN)=Z(4,I2)*ABZ3
      MTH(MN)=0.
      MXT(MN)=0.
      QS(MN)=0.
      TX(MN)=0.
      TTH(MN)=0.
      TTX(MN)=0.
      IF(M1.EQ.0) GO TO 1203
1202     CALL INLPOL
      M1L=M1-1
      M2L=M2-1
      PHIX(M1)=PHEE*ABZO
      PHIX(M1L)=PHEN*ABZO
      PHIT(M1)=-PHEE*ABZO

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PHIT(MIL)=PHIX(MIL)	00001790
QS(MI)=0.	00001800
QS(MIL)=0.	00001810
IF(MO.EQ.0) GO TO 1204	00001820
TX(M2)=TX*ABZ	00001830
MTH(M2)=TO*ABZ	00001840
MTH(M2)=MX(M2)	00001850
1204 IF(M2.EQ.0) GO TO 1205	00001860
TX(M2)=T2*ABZ	00001870
TTH(M2)=-T2*ABZ	00001880
TX(M2)=-T2*ABZ	00001890
MTH(M2)=-MX(M2)	00001900
MTH(M2)=MTH(M2)	00001910
TX(M2L)=T2N*ABZ	00001920
TTH(M2L)=-TX(M2L)	00001930
TX(M2L)=TX(M2L)	00001940
MTH(M2L)=-MX(M2L)	00001950
MTH(M2L)=MX(M2L)	00001960
GO TO 1205	00001970
1203 IF(MO.EQ.0) GO TO 1206	00001980
I3=3+(M2-1)*KMAX2	00001990
I4=I3+1	00002000
CALL TLOAD(1)	00002010
TX(M2)=BS*SI*((2.*Z(1,I3)-.5*Z(1,I4))/DEL+OMXI(1)*Z(3,I3-1))*ABZ	00002020
1 TX(M2)=-TX(MO)*ABZ*ALOAD	00002030
TTH(M2)=TX(MO)	00002040
MTH(M2)=MX(MO)	00002050
1206 IF(M2.EQ.0) GO TO 1205	00002060
I3=3+(M2-1)*KMAX2	00002070
I4=I3+1	00002080
TX(M2)=BS*D1*((2.*Z(1,I3)-.5*Z(1,I4))/DEL	00002090
TX(M2)=TX(M2)*ABZ	00002100
TTH(M2)=-TX(M2)	00002110
TX(M2)=-TX(M2)	00002120
MTH(M2)=-MX(M2)	00002130
MTH(M2)=-MX(M2)	00002140
TX(M2L)=BS*D1*((2.*Z(1,I3-KMAX2)-.5*Z(1,I4-KMAX2))/DEL	00002150
TX(M2L)=TX(M2L)*ABZ	00002160
TTH(M2L)=-TX(M2L)	00002170
TX(M2L)=TX(M2L)	00002180
MTH(M2L)=-MX(M2L)	00002190
MTH(M2L)=MX(M2L)	00002200
1205 RETURN	00002210
1301 CONTINUE	00002220
DO 1302 MN=1,MNMAXO	00002230
U1(MN)=U2(MN)	00002240
V1(MN)=V2(MN)	00002250
W1(MN)=W2(MN)	00002260





PHIX(MN)=0.	00002270
PHIT(MN)=0.	00002280
PHI(MN)=0.	00002290
IK=KMAX1+(MN-1)*KMAX2	00002300
MX(MN)=Z(4,IK)*ABZ3	00002310
MTH(MN)=0.	00002320
MXT(MN)=0.	00002330
QS(MN)=0.	00002340
TX(MN)=0.	00002350
TTH(MN)=0.	00002360
TXT(MN)=0.	00002370
IF(M1.EQ.0) GO TO 1303	00002380
CALL FNLPOL	00002390
PHIX(M1)=PHEE*ABZO	00002400
PHIX(M1L)=PHEN*ABZO	00002410
PHIT(M1)=PHEE*ABZO	00002420
PHIT(M1L)=PHIX(M1L)	00002430
QS(M1)=0.	00002440
QS(M1L)=0.	00002450
IF(MO.EQ.0) GO TO 1304	00002460
TX(MO)=TO*ABZ	00002470
TTH(MO)=TO*ABZ	00002480
MTH(MO)=MX(MO)	00002490
IF(M2.EQ.0) GO TO 1305	00002500
TX(M2)=T2*ABZ	00002510
TTH(M2)=-T2*ABZ	00002520
TXT(M2)=T2*ABZ	00002530
MTH(M2)=-MX(M2)	00002540
MXT(M2)=MX(M2)	00002550
TX(M2L)=T2N*ABZ	00002560
TTH(M2L)=-TX(M2L)	00002570
TXT(M2L)=-TX(M2L)	00002580
MTH(M2L)=-MX(M2L)	00002590
MXT(M2L)=-MX(M2L)	00002600
GO TO 1305	00002610
IF(MO.EQ.0) GO TO 1306	00002620
IKM=KMAX+(MO-1)*KMAX2	00002630
IM1=IKM-1	00002640
CALL TLOAD(KMAX)	00002650
TX(MO)=BS*SI*(-2.*Z(1,IKM)+.5*Z(1,IM1))/DEL+OMXI(KMAX)*Z(3,IKM+1)	00002660
1 TX(MO)=BS*ABZ-TT(MO)*ABZ*ALOAD	00002670
TTH(MO)=TX(MO)	00002680
MTH(MO)=MX(MO)	00002690
IF(M2.EQ.0) GO TO 1305	00002700
IKM=KMAX+(M2-1)*KMAX2	00002710
IM1=IKM-1	00002720
TX(M2)=BS*D1*(-2.*Z(1,IKM)+.5*Z(1,IM1))/DEL	00002730
TX(M2)=TX(M2)*ABZ	00002740



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TTH(M2) = -TX(M2)
THT(M2) = -TX(M2)
MTH(M2) = -MX(M2)
MXT(M2) = MX(M2)
TX(M2L) = BS*DI*(-2.*Z(1,IKM-KMAX2)+.5*Z(1,IM1-KMAX2))/DEL
TX(M2L) = TX(M2L)*ABZ
TTH(M2L) = -TX(M2L)
THT(M2L) = -TX(M2L)
MTH(M2L) = -MX(M2L)
MXT(M2L) = MX(M2L)
RETURN
END

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1305

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C***** SUBROUTINE OUTPUT(IMODE)
C***** THIS SUBROUTINE PREPARES THE PRINTOUT MATERIAL. EVERY IPRINT *****
C***** CONVERGED SOLUTION IS PRINTED. THE FOURIER COEFFICIENTS OF THE *****
C***** IN PLANE FORCES, MERIDIONAL TRANSVERSE FORCE, CIRCUMFERENTIAL *****
C***** BENDING MOMENT, TWISTING MOMENT AND ROTATIONS CAN BE COMPUTED *****
C***** AND PRINTED WITH THE SOLUTION Z FOR THE FOURIER COEFFICIENTS *****
C***** OF THE THREE DISPLACEMENTS AND MERIDIONAL BENDING MOMENT. THIS *****
C***** OUTPUT MATERIAL IS CONVERTED FROM DIMENSIONLESS FORM TO DIMEN *****
C***** SIGNAL FORM HERE. ETC. THIS SUBROUTINE ALSO PERFORMS THE *****
C***** 1, IFREQ+1, 2IFREQ+1, ETC. COMPUTING THE TOTAL VALUES OF THE *****
C***** SUMMATION PROCESS FOR ROTATIONS AT THE NTHMAX POSITIONS *****
C***** AROUND THE CIRCUMFERENCE PRESCRIBED IN THE INPUT DATA. *****
C***** REAL NU, MT, MX, MTH, MXT, MTS, KX, KT, KXT, LAM, LAM2, MASS *****
C***** INTEGER /IBL2/ N(25), MNINIT *****
C***** COMMON /IBL3/ M0, M1, M2, M3 *****
C***** COMMON /IBL4/ KMAX, KL *****
C***** COMMON /IBL5/ IBCFNL, IBCFNL *****
C***** COMMON /IBL7/ MNMAXO, MAXD(25), MAXS(25), MAXSY(25), IS(25, 25), *****
C***** JS(25, 25), ID(25, 25), JD(25, 25), IJS(25) *****
C*****
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COMMON /IBL8/ LSTEP, ITR
COMMON /IBL10/ IFREQ, NTHMAX
COMMON /IBL11/ ICORFL, IPASS, JUMP, MPERFS
COMMON /IBL12/ KMAX1, KMAX2, NCONV
COMMON /IBL13/ ITRMAX, LSMA
COMMON /BL4/ P(4,4,951), X(4,951), ZF1M(4,4,25), ZF2M(4,4,25),
1 ZF3M(4,4,25), ZF4M(4,4,25)
COMMON /BL5/ TT(25), MT(25), DT(25), DMT(25)
COMMON /BL6/ Z(4,1001), SOE, OSE, ALOAD
COMMON /BL7/ D1, S1
COMMON /BL8/ R(100), GAM(100), OMT(100)
COMMON /BL10/ PHIX(25), PHIT(25), PHI(25)
COMMON /BL11/ OMXI(100), PHEE, IO, T2
COMMON /BL12/ TDLI, TDEL
COMMON /BL14/ LAM2, LSD18, LSD1N
COMMON /BL15/ NU, UI(25), U2(25), U3(25), V1(25), V2(25), V3(25), W1(25),
1 W2(25), W3(25)
COMMON /BL17/ DEL
COMMON /BL19/ TH(36)
COMMON /BL20/ DEOMX(100)
COMMON /BL27/ BX3(25), BT3(25), BXT3(25), BE3(25)
COMMON /BL31/ DELSQ, EXT1(25)
COMMON /BL32/ TKN, ELAST, CHAR, SIGO
COMMON /BL100/ SORD, TEEQ
COMMON /BL101/ ZQ(4,1001), Z2(4,1001), Z3(4,1001), DELSD
COMMON /BL102/ DELOAD
COMMON /BL103/ MASS(100)
COMMON /BL110/ TX(25), TTH(25), TXT(25), MX(25), MTH(25), MXT(25),
1 QS(25)
COMMON /BL111/ ABZ, ABZQ, ABZN, ABZ3, DD2
DIMENSION PTF(100), PF(100)
C*****
ABZQ=SIGO/ELAST
IF(SORD.NE.0) GO TO 181
WRITE(6,101) LSTEP, ALOAD, ITR
GO TO 182
181 TI=LSTEP*DELOAD
TI=TI*TEEQ
WRITE(6,151) LSTEP, TI, DTI, ITR
182 LAM=TKN/CHAR
ENL=1.
ABZ=SIGO*TKN
ABZ3=ABZ*TKN*TKN/CHAR
ABZN=CHAR*SIGO/ELAST
IF(ITRMAX.EQ.1) ENL=0.
DD2=1.-NU*2
DDI=1./DD2
DPI=1./S1
00000240
00000250
00000260
00000270
00000280
00000290
00000300
00000310
00000320
00000330
00000340
00000350
00000360
00000370
00000380
00000390
00000400
00000410
00000420
00000430
00000440
00000450
00000460
00000470
00000480
00000490
00000500
00000510
00000520
00000530
00000540
00000550
00000560
00000570
00000580
00000590
00000600
00000610
00000620
00000630
00000640
00000650
00000660
00000670
00000680
00000690
00000700
00000710

```



```

DNI=1./D1
TDLSQI=.5/DELSQ
IF(NTHMAX.EQ.0) GO TO 991
DO 21 NTH=1,NTHMAX
DO 1 MN=1,MNMAXO
I1=1+(MN-1)*KMAX2
I2=I1+1
U1(MN)=Z(1,I1)
U2(MN)=Z(1,I2)
V1(MN)=Z(2,I1)
V2(MN)=Z(2,I2)
W1(MN)=Z(3,I1)
W2(MN)=Z(3,I2)
THET=TH(NTH)
WRITE(6,116) THET
DO 121 K=1,KMAX
K1=K+1
CALL DB(K,BS,DB,DS,DD)
IF(K.EQ.1.AND.IBCINL.LT.0) CALL POLE(K)
IF(K.EQ.1.AND.IBCINL.LT.0) GO TO 999
IF(K.EQ.KMAX.AND.IBCFNL.LT.0) CALL POLE(K)
IF(K.EQ.KMAX.AND.IBCFNL.LT.0) GO TO 999
CALL PHIBET(K)
DEX=DECMX(K)
RRA=1./R(K)
OX=OMXI(K)
OT=OMT(K)
GA=GAM(K)
DOXT=OX-OT
GDO=GA*DOXT
DD2D=DD2*DS
DO 3 MN=1,MNMAXO
EN=N(MN)
ENR=EN*RRA
CALL TLOAD(K)
TTS=TT(MN)*ALOAD
EX=(U3(MN)-U1(MN))*TDLI+OX*W2(MN)+ENL*OSE*(BX3(MN)+BE3(MN))
ET=ENR*V2(MN)+OT*W2(MN)+ENL*OSE*(BT3(MN)+BE3(MN))
EXT=0.5*((V3(MN)-V1(MN))*TDLI-ENR*U2(MN)-GA*V2(MN)
      +ENL*SOE*BXT3(MN))
1 KT=ENR*PHIT(MN)+GA*PHIX(MN)
KXT=0.5*(-ENR*(-PHIX(MN)-GA*W2(MN)-(W3(MN)-W1(MN))*TDLI)+GDO*V2(MN)
      +OT*(V3(MN)-V1(MN))*TDLI-GA*PHIT(MN)-DOXT*PHI(MN))
1 TX(MN)=BS*(EX+NU*ET)-TTS
TTH(MN)=BS*(ET+NU*EXT)
TXT(MN)=BS*D1*EXT
MK1=K1+(MN-1)*KMAX2
MX(MN)=Z(4,MK1)

```





```

MTH(MN)=NU*MX(MN)+DD2D*KT-D1*MT(MN)*ALOAD
MXT(MN)=DS*D1*KXT
MK11=MK1+1
MKK1=MK1-1
QS(MN)=SIGO*TKN*LAM2*(GA*MX(MN)+(Z(4,MK11)-Z(4,MKK1))*TDLI
1  +ENR*MXT(MN)-GA*MTH(MN)
MX(MN)=MX(MN)*ABZ3
MTH(MN)=MTH(MN)*ABZ3
MXT(MN)=MXT(MN)*ABZ3
TX(MN)=TX(MN)*ABZ
TTH(MN)=TTH(MN)*ABZ
THT(MN)=THT(MN)*ABZ
PHIX(MN)=PHIX(MN)*ABZO
PHIT(MN)=PHIT(MN)*ABZO
PHI(MN)=PHI(MN)*ABZO
U1(MN)=U2(MN)
U2(MN)=U3(MN)
V1(MN)=V2(MN)
V2(MN)=V3(MN)
W1(MN)=W2(MN)
W2(MN)=W3(MN)
3  FK=K-1
FIFREQ=IFREQ
KTST=(K-1)/IFREQ
FKTST=KTST
FKTEST=FK/FIFREQ-FKTST
IF(K.EQ.1-OR.K.EQ.KMAX) GO TO 999
IF(FKTEST.NE.0.) GO TO 2
999 X(1,K)=0.
X(2,K)=0.
X(3,K)=0.
X(4,K)=0.
PTF(K)=0.
PF(K)=0.
AMX=0.
AMTH=0.
AMXTH=0.
ANX=0.
ANTH=0.
ANXTH=0.
AQS=0.
IF (JUMP.EQ.2) GO TO 73
DO 72 MN=1,MNMAXO
EN=N(MN)
FC=EN*THET
SN=SIN(FC)
CS=COS(FC)
X(1,K)=X(1,K)+U1(MN)*CS*ABZN
00001200
00001210
00001220
00001230
00001240
00001250
00001260
00001270
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00001290
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00001490
00001500
00001510
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00001530
00001540
00001550
00001560
00001570
00001580
00001590
00001600
00001610
00001620
00001630
00001640
00001650
00001660
00001670

```



```

X(2,K)=X(2,K)+V1(MN)*SN*ABZN
X(3,K)=X(3,K)+W1(MN)*CS*ABZN
X(4,K)=X(4,K)+PHIX(MN)*CS
PTF(K)=PTF(K)+PHIT(MN)*SN
AMX=AMX+MX(MN)*CS
AMTH=AMTH+MTH(MN)*CS
AMXTH=AMXTH+MXTH(MN)*SN
ANX=ANX+TX(MN)*CS
ANTH=ANTH+TTH(MN)*CS
AQS=AQS+QS(MN)*CS
ANXTH=ANXTH+TXTH(MN)*SN
PF(K)=PF(K)+P+I(MN)*SN
GO TO 429
72 DO 74 MN=3,MNMAXO,JUMP
EN=N(MN)
FC=EN*THET
SN=SIN(FC)
CS=COS(FC)
MNM=MN-1
X(1,K)=X(1,K)+(U1(MN)*CS+U1(MNM)*SN)*ABZN
X(2,K)=X(2,K)+(V1(MN)*SN+V1(MNM)*CS)*ABZN
X(3,K)=X(3,K)+(W1(MN)*CS+W1(MNM)*SN)*ABZN
X(4,K)=X(4,K)+PHIX(MN)*CS+PHIX(MNM)*SN
PTF(K)=PTF(K)+PHIT(MN)*SN+PHIT(MNM)*CS
AMX=AMX+MX(MN)*CS+MX(MNM)*SN
AMTH=AMTH+MTH(MN)*CS+MTH(MNM)*SN
AMXTH=AMXTH+MXTH(MN)*SN+MXTH(MNM)*CS
ANX=ANX+TX(MN)*CS+TX(MNM)*SN
ANTH=ANTH+TTH(MN)*CS+TTH(MNM)*SN
ANXTH=ANXTH+TXTH(MN)*SN+TXTH(MNM)*CS
AQS=AQS+QS(MN)*CS+QS(MNM)*SN
PF(K)=PF(K)+PHI(MN)*SN+PHI(MNM)*CS
X(1,K)=X(1,K)+U1(1)*ABZN
X(2,K)=X(2,K)+V1(1)*ABZN
X(3,K)=X(3,K)+W1(1)*ABZN
X(4,K)=X(4,K)+PHIX(1)
PTF(K)=PTF(K)+PHIT(1)
PF(K)=PF(K)+PHI(1)
AMX=AMX+MX(1)
AMTH=AMTH+MTH(1)
AMXTH=AMXTH+MXTH(1)
ANX=ANX+TX(1)
ANTH=ANTH+TTH(1)
ANXTH=ANXTH+TXTH(1)
AQS=AQS+QS(1)
CONTINUE
429 IF(K.EQ.1) WRITE(6,117)
IF((K.EQ.1).AND.IBCINL.LT.0).OR.(K.EQ.KMAX.AND.IBCFNL.LT.0))

```

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00001680
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00002010
00002020
00002030
00002040
00002050
00002060
00002070
00002080
00002090
00002100
00002110
00002120
00002130
00002140
00002150

```



```

1 GO TO 220
  GO TO 221
220 WRITE (6,1181) K,ANX,ANTH,ANXTH,AMX,AMTH,AMXTH
  GO TO 2
221 WRITE(6,118) K,ANX,ANTH,ANXTH,AQS,AMX,AMTH,AMXTH
121 CONTINUE
  CONTINUE
DO 660 K=1,KMAX
  FK=K-1
  FIFREQ=IFREQ
  KTST=(K-1)/IFREQ
  FKST=KTST
  FKTEST=FK/FIFREQ-FKST
  IF(K.EQ.1.OR.K.EQ.KMAX) GO TO 661
  IF(FKTEST.NE.0.) GO TO 658
  IF(K.EQ.1) WRITE(6,217)
  WRITE(6,218) K,X(1,K),X(2,K),X(3,K),X(4,K),PTF(K),PF(K)
661 DO 659 I=1,4
659 X(I,K)=0.
660 CONTINUE
991 IF(IMODE.LE.0) RETURN
DO 534 MN=1,MNMAXO
  WRITE(6,749) N(MN)
DO 521 MM=1,MNMAXO
  I1=1+(MM-1)*KMAX2
  I2=I1+1
  U1(MM)=Z(1,I1)
  U2(MM)=Z(1,I2)
  V1(MM)=Z(2,I1)
  V2(MM)=Z(2,I2)
  W1(MM)=Z(3,I1)
  W2(MM)=Z(3,I2)
521 CONTINUE
DO 445 K=1,KMAX
  K1=K+1
  CALL BDB(K,BS,DB,DS,DD)
  IF(K.EQ.1.AND.IBCINL.LT.0) CALL POLE(K)
  IF(K.EQ.KMAX.AND.IBCFNL.LT.0) CALL POLE(K)
  TXZ=TX(MN)
  TTHZ=TTH(MN)
  TX1Z=TX1(MN)
  AMXZ=MX(MN)
  AMTHZ=MTH(MN)
  AMXTZ=MXT(MN)
  QSZ=QS(MN)
  X(1,K)=PHIX(MN)
  X(2,K)=PHIT(MN)

```

```

00002160
00002170
00002180
00002190
00002200
00002210
00002220
00002230
00002240
00002250
00002260
00002270
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00002290
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00002490
00002500
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00002540
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00002570
00002580
00002590
00002600
00002610
00002620
00002630

```



```

X(3,K)=PHI(MN)
IF(K.EQ.1.AND.IBCINL.LT.0) GO TO 583
IF(K.EQ.KMAX.AND.IBCFNL.LT.0) GO TO 583
CALL PHIBET(K)
DEX=DEOMX(K)
RRA=1./R(K)
OX=OMXI(K)
OT=OMT(K)
GA=GAM(K)
DOXT=OX-OT
GDO=GA*DOXT
DD2D=DD2*DS
EN=N(MN)
ENR=EN*RA
CALL TLOAD(K)
TTS=TT(MN)*ALOAD
EX=(U3(MN)-U1(MN))*TDLI+OX*W2(MN)+ENL*OSE*(BX3(MN)+BE3(MN))
ET=ENR*V2(MN)+GA*U2(MN)+OT*W2(MN)+ENL*OSE*(BT3(MN)+BE3(MN))
EXT=.5*((V3(MN)-V1(MN))*TDLI-ENR*U2(MN)-GA*V2(MN)
1      +ENL*SOE*BX3(MN))
KT=ENR*PHIT(MN)+GA*PHIX(MN)
KXT=.5*(ENR*(-PHIX(MN)-GA*W2(MN)+(W3(MN)-W1(MN))*TDLI)+GDO*V2(MN)
1      +OT*(V3(MN)-V1(MN))*TDLI-GA*PHIT(MN)-DOXT*PHI(MN))
TXZ=(BS*(EX+NU*ET)-TTS)*ABZ
TTHZ=(BS*(ET+NU*EX)-TTS)*ABZ
TXTZ=BS*DI*EXT*ABZ
MK1=K1+(MN-1)*KMAX2
AMXZ=Z(4,MK1)
AMTHZ=NU*AMXZ+DD2D*KT-D1*MT(MN)*ALOAD
AMXTZ=DS*D1*KXT
MK11=MK1+1
MKK1=MK1-1
QSZ=SIGO*TKN*LAM2*(GA*AMXZ+(Z(4,MK11)-Z(4,MKK1))*TDLI
1      +ENR*AMXTZ-GA*AMTHZ)
AMXZ=AMXZ*ABZ3
AMTHZ=AMTHZ*ABZ3
AMXTZ=AMXTZ*ABZ3
X(1,K)=PHIX(MN)*ABZO
X(2,K)=PHIT(MN)*ABZO
X(3,K)=PHI(MN)*ABZO
DO 533 MM=1,MNMAXO
U1(MM)=U2(MM)
U2(MM)=U3(MM)
V1(MM)=V2(MM)
V2(MM)=V3(MM)
W1(MM)=W2(MM)
W2(MM)=W3(MM)
FK=K-1
533

```









```

1 M THETA 14H M STHETA 14H N S 14H N THETA 14H 1400003600
2H N STHETA 14H Q S 00003610
114 FORMAT(2X,I2,3X,7E16.4) 00003620
115 FORMAT(7H N 16H M S 16H THETA 16H N THETA 16H N 00003630
1 STHETA 16H M S 16H THETA 15H M STHETA//) 00003640
116 FORMAT(1H0,84H THE SUMMED FORCES, MOMENTS, DISPLACEMENTS 00003650
1 AND ROTATIONS FOLLOW FOR THETA=E15.6//) 00003660
117 FORMAT(//,8H STATION15H N S 16H N THETA 16H M THETA 00003670
1 IN STHETA 16H Q S 16H M S 00003680
216H M STHETA //) 00003690
118 FORMAT(1X,I3,3X,7E16.4) 00003700
1181 FORMAT(1X,I3,3X,3E16.4) NOT COMPUTED ',3E16.4) 00003710
151 FORMAT(1H1,26H THE TIME STEP THE TIME IS F500003720
1,2,4H OR E9.3,40H SECONDS THE SOLUTION CONVERGED IN I2,I1H IT 00003730
3ERATIONS//) 00003740
217 FORMAT(//8H STATION,15H U 16H V 16H 00003750
1 W 16H PHI THETA16H PHI 00003760
2 /) 00003770
218 FORMAT(1X,I3,3X,6E16.4) 00003780
749 FORMAT(1H1,40X,27H MODAL OUTPUT FOR MODE N = I3,8H FOLLOWS) 00003790
RETURN 00003800
END 00003810
00003820

```

```

C *****
C SUBROUTINE IMPERF
C COMMON /IBL1/ ICORFL,IPASS,JUMP,MPERFS
C COMMON /BLIMP/ PHIXB(951),PHITB(951)
C DIMENSION FNT(25),DFNT(25)
C *****
C THIS SUBROUTINE EITHER CAN COMPUTE THE INITIAL IMPERFECTIONS OF
C THE SHELL AND INITIALIZE ARRAYS PHIXB AND PHITB, OR JUST CAUSE
C A LOADING OF THE ARRAYS FROM PRE-PPREPARED DATA CARDS. IF 'MPERFS'
C IS 0, THE ARRAYS PHIXB AND PHITB ARE MADE ZERO. THE IMPERFECTION
C NOTE: WHEN LOADING ARRAYS PHIXB AND PHITB WITH THE FOLLOWING ORDERING MUST BE
C ROTATION FOURIER COEFFICIENTS, THE FOLLOWING ORDERING MUST BE
C FOLLOWED: FIRST KMAX LOCATIONS CONTAIN MODE '0',
C SECOND KMAX LOCATIONS CONTAIN MODE '-1',
C *****

```



```

C      THIRD KMAX LOCATIONS CONTAIN MODE '+I',
C      FOURTH KMAX LOCATIONS CONTAIN MODE '-J',
C      FIFTH KMAX LOCATIONS CONTAIN MODE '+J',
C      SIXTH KMAX LOCATIONS CONTAIN MODE '-K', ETC.
C      IF (IMPERFS.EQ.1) GO TO 2
C      DO 1 I=1,951
C      PHITB(I)=0.0
C      1 GO TO 3
C      2 CONTINUE
C      FROM HERE TO THE NEXT ROW OF ASTERISKS IS WHERE THE COEFFICIENTS
C      ARE EITHER COMPUTED AND READ, OR JUST READ.
C      READ (5,1002)(PHIXB(I),I=1,875)
C      READ (5,1002)(PHITB(I),I=1,875)
C      1002 FORMAT (174(5E14.6/),5E14.6)
C      FOLLOWING CARDS REDUCE IMPERFECTIONS TO 'MINUTE' SIZE.
C      DO 7 I=1,875
C      PHIXB(I)=PHIXB(I)*0.0001
C      7 PHITB(I)=PHITB(I)*0.0001
C      3 RETURN
C      END

```



# APPENDIX G

## LISTING OF IMPERFECTION DATA HANDLING PROGRAM

```

C      PROGRAM TO PREPARE RAW IMPERFECTION DATA FOR USE BY SATANS-II
DIMENSION A14(1422),AM14(35,49),PHIXRO(35,49),PHITRO(35,49),
1      TEMP(48),A(25),B(25),PXROCC(35,25),PXROSC(35,25),
2      PTRJCC(35,25),PTRJSC(35,25),PXRCSCS(25),PXRS(25),
3      PTRCCS(25),PTRSCS(25),CHECK(361),C(25),S(25),NN(13),
4      PHIXB(951),PHITB(951),E(25)
C
C      READ RAW DATA INTO COLUMN MATRIX, A14:
C
DO 1 I=1,237
K=6*(I-1)
1 READ (5,1000) A14(K+1),A14(K+2),A14(K+3),A14(K+4),A14(K+5),
A14(K+6)
C
C      TRANSFER DATA INTO 35X49 MATRIX: (NOTE - ROWS 1,2,3,33,34,35 ARE
C      UNKNOWN AT THIS POINT)
C      IN THE PROCESS, DIMENSIONALIZE THE DATA (MULT. BY SHELL THICKNESS)
C
K=0
DO 2 I=4,32
DO 2 J=1,49
K=K+1
2 AM14(I,J)=A14(K)*0.00437
C
C      PERFORM MODIFIED LINEAR EXTRAPOLATION FOR END POINTS
C
DO 3 J=1,49
D1=(AM14(4,J)+AM14(5,J))/2.0
D2=(AM14(6,J)+AM14(7,J))/2.0
D3=(AM14(32,J)+AM14(31,J))/2.0
D4=(AM14(30,J)+AM14(29,J))/2.0
THETAT=(D1-D2)/0.48
THETAB=(D3-D4)/0.48
AM14(3,J)=D1+THETAT*0.36
AM14(2,J)=D1+THETAT*0.6
AM14(1,J)=D1+THETAT*0.84
AM14(33,J)=D3+THETAB*0.36
AM14(34,J)=D3+THETAB*0.6
3 AM14(35,J)=D3+THETAB*0.84
C
C      FULL 35X49 MATRIX OF DIMENSIONAL DEVIATIONS EXISTS.
C

```





```

C C C
WRITE (6,1001)
WRITE (6,1002)
WRITE (6,1003) ((AM14(I,J),J=1,49),I=1,35)
COMPUTE MERIDIONAL ROTATIONS USING FINITE DIFFERENCING
DO 4 J=1,49
DO 5 I=2,34
IM1=I-1
JPI=I+1
5 PHIXRO(I,J)=(AM14(IM1,J)-AM14(JPI,J))/0.48
4 PHIXRO(I,J)=PHIXRO(2,J)
PHIXRO(35,J)=PHIXRO(34,J)
COMPUTE CIRCUMFERENTIAL ROTATIONS IN SIMILAR FASHION
NOTE: SPACING EQUALS CIRCUMFERENCE/INCREMENTS = PI/6)
DO 6 I=1,35
DO 7 J=2,48
JM1=J-1
JPI=J+1
7 PHITRO(I,J)=(AM14(I,JM1)-AM14(I,JPI))/1.047198
6 PHITRO(I,J)=PHITRO(1,J)
FULL 35X49 MATRICES OF MERIDIONAL AND CIRCUMFERENTIAL ROTATIONS
EXIST.
C C C C
WRITE (6,1001)
WRITE (6,1004)
WRITE (6,1003) ((PHIXRO(I,J),J=1,49),I=1,35)
WRITE (6,1001)
WRITE (6,1005) ((PHITRO(I,J),J=1,49),I=1,35)
WRITE (6,1003)
NONDIMENSIONALIZE THE PHIXRO AND PHITRO MATRICES FOR USE BY
SATANS-II - MULTIPLY BY EO/SIGO
C C C C
DO 77 I=1,35
DO 77 J=1,49
PHIXRO(I,J)=PHIXRO(I,J)*0.158E5
77 PHITRO(I,J)=PHITRO(I,J)*0.158E5
WRITE (6,1001)
WRITE (6,2004) ((PHIXRO(I,J),J=1,49),I=1,35)
WRITE (6,1003)
WRITE (6,1001)
WRITE (6,2005) ((PHITRO(I,J),J=1,49),I=1,35)
WRITE (6,1003)

```







C

```

DO 15 J=1,25
PXCSUM=0.0
PXSSUM=0.0
PTCSSUM=0.0
PTSSUM=0.0
DO 16 I=1,35
PXCSUM=PXCSUM+ABS(PXROCC(I,J))
PXSSUM=PXSSUM+ABS(PXROSC(I,J))
PTCSSUM=PTCSSUM+ABS(PTROCC(I,J))
PTSSUM=PTSSUM+ABS(PTROSC(I,J))
16 PXRCCS(J)=PXCSUM/35.0
PXRSCS(J)=PXSSUM/35.0
PTRCCS(J)=PTCSSUM/35.0
PTRSCS(J)=PTSSUM/35.0
WRITE (6,1001)
DO 17 I=1,25
J=I-1
17 WRITE (6,1010) J,PXRCCS(I),PXRSCS(I),PTRCCS(I),PTRSCS(I)

```

C  
C  
C

PICK CIRCUMFERENCE 10 AND COMPARE ACTUAL VS FOURIER REPRESENTATION  
OF CIRCUMFERENTIAL ROTATION IMPERFECTION.

```

DO 18 I=1,25
A(I)=PTROCC(10,I)
B(I)=PTROSC(10,I)
STEP=.1745329E-1
DO 19 I=1,361
THETA=FLOAT(I-1)*STEP
DO 20 J=2,25
RJ=FLOAT(J-1)
C(J)=A(J)*COS(RJ*THETA)
S(J)=B(J)*SIN(RJ*THETA)
20 CHECK(I)=A(I)
DO 21 J=2,25
CHECK(I)=CHECK(I)+C(J)+S(J)
21 CONTINUE
19 WRITE (6,1001)
WRITE (6,1011)
K=1
DO 22 I=1,361,15
II=I-1
22 WRITE (6,1012) II,PHITRO(10,K),CHECK(I)
K=K+2
DO 23 I=1,90
II=I-1

```



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00002310
00002320
00002330
00002340

I2=I1+90
I3=I1+180
I4=I1+270
23 WRITE (6,1014) I1,CHECK(I),I2,CHECK(I+90),I3,CHECK(I+180),I4,
   CHECK(I+270)
C
IF MODES FOR USE BY SATANS-II ARE KNOWN REMOVE 'GO-TO' AND PROCEED
GO TO 9999
C
READ MODES TO BE USED IN SATANS-II ANALYSIS
NOTE: MODES MUST INCLUDE MODE '0',
C
231 READ (5,1015) (NN(I),I=1,13)
   WRITE (6,1001)
   WRITE (6,1020) (NN(I),I=1,13)
C
SINCE MODE '0' LIVES IN SLOT '1', ETC., BOUNCE EACH VALUE 1.
C
DO 24 I=1,13
24 NN(I)=NN(I)+1
C
SEE HOW CIRC. 10 LOOKS WITH THESE SELECTED MODES.
DO 25 I=1,361
THETA=FLOAT(I-1)*STEP
DO 26 J=2,13
RJ=FLOAT(NN(J)-1)
C(NN(J))=A(NN(J))*COS(RJ*THETA)
S(NN(J))=B(NN(J))*SIN(RJ*THETA)
CHECK(I)=A(1)
DO 27 J=2,13
CHECK(I)=CHECK(I)+C(NN(J))+S(NN(J))
27 CONTINUE
25 WRITE (6,1013)
DO 28 I=1,90
I1=I-1
I2=I1+90
I3=I1+180
I4=I1+270
28 WRITE (6,1014) I1,CHECK(I),I2,CHECK(I+90),I3,CHECK(I+180),I4,
   CHECK(I+270)
C
PUT APPROPRIATE ROTATION IMPERFECTION COEFFS INTO ARRAYS 'PHIXB'
AND 'PHITB' FOR USE BY SATANS-II.
NOTE: ORDER IN WHICH SATANS-II USES PHIXB & PHITB IS AS FOLLOWS:
FIRST KMAX LOCNS ARE MODE '0',
SECOND KMAX LOCNS ARE MODE '1',
THIRD KMAX LOCNS ARE MODE 'I',
FOURTH KMAX LOCNS ARE MODE 'I-J'
C

```





C  
C  
C

FIFTH KMAX LOCNS ARE MODE 'J',  
SIXTH KMAX LOCNS ARE MODE '-K', ETC.....

```
DO 101 I=1,35
PHIXB(I)=PXROCC(I,1)
PHITB(I)=PTROCC(I,1)
101 DO 102 I=1,35
II=I+70
JJ=I-35
PHIXB(II)=PXROCC(I,NN(2))
PHITB(II)=PTROCC(I,NN(2))
PHIXB(JJ)=PXROSC(I,NN(2))
PHITB(JJ)=PTROSC(I,NN(2))
102 DO 103 I=1,35
II=I+140
JJ=I-35
PHIXB(II)=PXROCC(I,NN(3))
PHITB(II)=PTROCC(I,NN(3))
PHIXB(JJ)=PXROSC(I,NN(3))
PHITB(JJ)=PTROSC(I,NN(3))
103 DO 104 I=1,35
II=I+210
JJ=I-35
PHIXB(II)=PXROCC(I,NN(4))
PHITB(II)=PTROCC(I,NN(4))
PHIXB(JJ)=PXROSC(I,NN(4))
PHITB(JJ)=PTROSC(I,NN(4))
104 DO 105 I=1,35
II=I+280
JJ=I-35
PHIXB(II)=PXROCC(I,NN(5))
PHITB(II)=PTROCC(I,NN(5))
PHIXB(JJ)=PXROSC(I,NN(5))
PHITB(JJ)=PTROSC(I,NN(5))
105 DO 106 I=1,35
II=I+350
JJ=I-35
PHIXB(II)=PXROCC(I,NN(6))
PHITB(II)=PTROCC(I,NN(6))
PHIXB(JJ)=PXROSC(I,NN(6))
PHITB(JJ)=PTROSC(I,NN(6))
106 DO 107 I=1,35
II=I+420
JJ=I-35
PHIXB(II)=PXROCC(I,NN(7))
PHITB(II)=PTROCC(I,NN(7))
PHIXB(JJ)=PXROSC(I,NN(7))
PHITB(JJ)=PTROSC(I,NN(7))
107
```



DO 108	I=1,35		00002830
II=I+490			00002840
JJ=I-35			00002850
PHIXB(II)	=PXROCC(I, NN(8))		00002860
PHITB(II)	=PTRJCC(I, NN(8))		00002870
PHIXB(JJ)	=PXROSC(I, NN(8))		00002880
PHITB(JJ)	=PTRJSC(I, NN(8))		00002890
DO 109	I=1,35		00002900
II=I+560			00002910
JJ=I-35			00002920
PHIXB(II)	=PXROCC(I, NN(9))		00002930
PHITB(II)	=PTRJCC(I, NN(9))		00002940
PHIXB(JJ)	=PXROSC(I, NN(9))		00002950
PHITB(JJ)	=PTRJSC(I, NN(9))		00002960
DO 110	I=1,35		00002970
II=I+630			00002980
JJ=I-35			00002990
PHIXB(II)	=PXROCC(I, NN(10))		00003000
PHITB(II)	=PTRJCC(I, NN(10))		00003010
PHIXB(JJ)	=PXROSC(I, NN(10))		00003020
PHITB(JJ)	=PTRJSC(I, NN(10))		00003030
DO 111	I=1,35		00003040
II=I+700			00003050
JJ=I-35			00003060
PHIXB(II)	=PXROCC(I, NN(11))		00003070
PHITB(II)	=PTRJCC(I, NN(11))		00003080
PHIXB(JJ)	=PXROSC(I, NN(11))		00003090
PHITB(JJ)	=PTRJSC(I, NN(11))		00003100
DO 112	I=1,35		00003110
II=I+770			00003120
JJ=I-35			00003130
PHIXB(II)	=PXROCC(I, NN(12))		00003140
PHITB(II)	=PTRJCC(I, NN(12))		00003150
PHIXB(JJ)	=PXROSC(I, NN(12))		00003160
PHITB(JJ)	=PTRJSC(I, NN(12))		00003170
DO 113	I=1,35		00003180
II=I+840			00003190
JJ=I-35			00003200
PHIXB(II)	=PXROCC(I, NN(13))		00003210
PHITB(II)	=PTRJCC(I, NN(13))		00003220
PHIXB(JJ)	=PXROSC(I, NN(13))		00003230
PHITB(JJ)	=PTRJSC(I, NN(13))		00003240
WRITE	(6,1001)		00003250
WRITE	(6,1016)	( PHIXB(I), I=1,875)	00003260
WRITE	(6,1017)		00003270
WRITE	(6,1001)		00003280
WRITE	(6,1018)		00003290
WRITE	(6,1017)	( PHITB(I), I=1,875)	00003300







```

SUBROUTINE FORIER (LP,Y,M,AH0,SYS,A,B,E)
GIVEN A SET OF LP DATA POINTS Y(Q), EQUALLY SPACED, FORIER WILL DETER
MINE LP CONSTANTS SO THAT EITHER EQUATION B.1 OR B.2 BELOW IS
SATISFIED:
    IF LP BE AN ODD NUMBER, THEN N IS TAKEN AS (L-1)/2, AND;
B.1:
    P=1/_
    Y(N)=A(0)/2 + SUM/ A(P)COS(2PI*NP/(2N+1)) + B(P)SIN(2PI*NP/(2N+1)) /_
    WHERE N=0,1,2,...,2N
B.2
    IF LP BE AN EVEN NUMBER, THEN N IS TAKEN AS L/2 AND;
    N-1/_
    Y(N)=A(0)/2+SUM/ (A(P)COS(PI*NP/N)+B(P)SIN(PI*NP/N))+A(N)COS(PI*N))/2/_
    P=1/_
    WHERE N=0,1,2,...,2N-1
CONTINUE
ARGUMENTS:
LP:  NUMBER OF DATA POINTS TO BE FITTED, AN INTEGER. THIS
IS THE NJMBER OF ITEMS IN THE Y ARRAY TO BE CONSIDERED
BY FORIER. (DO NOT INCLUDE THE POINT AT 2PI)
Y:   DATA ARRAY TO BE DECLARED IN USER'S DIMENSION STATEMENT
AS A REAL*4. IT MUST CONTAIN AT LEAST LP MEANGFUL
ITEMS. Y DATA ARE ALWAYS TAKEN TO BE EQUALLY SPACED.
M:   HIGHEST HARMONIC TO BE CONSIDERED IN MAKING THE FIT, AN
INTEGER. IF M<=0 OR M>N, THEN THE EFFECTIVE M USED BY
FORIER WILL BE TAKEN AS EQUAL TO N.
AH0: THE RESULT A(0)/2.
SYS: THE SUM OF Y**2.
A:   AN ARRAY DECLARED IN USER'S DIMENSION STATEMENT. A(1)
CONTAINS THE FOURIER COEFFICIENT A1, A(2) CONTAINS A2, ETC.
NOTE: A(N) CONTAINS A(N/2) WHEN LP IS AN EVEN NUMBER.
NOTE: A MUST BE DIMENSIONED AT LEAST N IN SIZE.
B:   SIMILAR TO THE A ARRAY. CONTAINS THE SINE COEFFICIENTS.
NOTE: WHEN LP IS EVEN, B(N) IS SET TO 0.0.
E:   AN ARRAY DECLARED IN USER'S DIMENSION STATEMENT. E(I)
CONTAINS THE SUM OF THE SQUARES OF THE ERRORS IN THE FIT
WHEN TERMS ONLY UP TO I, HARMONICS ARE USED. IF N HARMONICS
ARE USED, E(N) IS ZERO BY DEFINITION BUT IS CALCULATED
ANALYTICALLY TO PROVIDE SOME CONTROL ON ACCURACY OF CALC.

DIMENSION Y(1),A(1),B(1),E(1)
L=LP

```





```

11 LM1=L-1
12 IL=2
10 N=L/2
14 IF(2*N-L)12,10,11
15 STOP
16 IL=1
17 IF(M)15,15,14
18 ME=M
19 IF(M-N)16,16,15
20 ME=N
21 SUMYS=0.0
22 DO 13 I=1,L
23 SUMYS=SUMYS+Y(I)**2
24 SYS=SUMYS
25 C=1.0
26 Q=2.0
27 S=0.0
28 FL=L/2.0
29 FN=FL/2.0
30 CON1=6.2831853/FL
31 C1=COS(CON1)
32 S1=SIN(CON1)
33 CON2=2.0/FL
34 IM=1
35 DO 28 J=1,N
36 IP=J-1
37 U2=0.0
38 U1=0.0
39 LN=L
40 DO 23 K=1,LM1
41 U0=Y(LN)+Q*U1-U2
42 U2=U1
43 U1=U0
44 LN=LV-1
45 AAA=CON2*(Y(1)+C*U1-U2)
46 IF(IP)11,250,251
47 AHO=AAA/2.0
48 SUMC=AHO*AAA
49 GO TO 26
50 GO TO (252,252,253),IM
51 A(IP)=AAA
52 B(IP)=CON2*S*U1
53 SUMC=SUMC+A(IP)**2+B(IP)**2
54 E(IP)=SUMYS-FN*SUMC
55 IF(IP-ME)27,33,11
56 Q=C1*C-S1*S
57 S=C1*S+S1*C
58 C=0

```



```

28  Q=C+Q
    IM=IM+IL
    IP=N
    GO TO 255
253  A(N)=AAA/2.0
    B(N)=0.0
    SUMC=SUMC+A(N)*AAA
    GO TO 254
33  RETURN
    END

```

```

00004730
00004740
00004750
00004760
00004770
00004780
00004790
00004800
00004810
00004820

```



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13. ABSTRACT A digital computer program for the geometrically nonlinear static and dynamic response of arbitrarily loaded shells of revolution known as SATANS is modified, removing a requirement that the applied loads be symmetric about a datum meridional plane. The ability to include arbitrary naturally-occurring initial geometric imperfections of any shape, location or extent is added to the program. Two specific axially loaded circular cylinders are analyzed using actual initial imperfec- tions. Detailed numerical studies are conducted to determine the buckling loads of the perfect and imperfect cylinders. Several sets of boundary conditions are considered. An analysis procedure for imperfect shells is proposed. The results indicate that a means to conduct a numerical analysis of an arbitrarily imperfect shell of revolution has been developed. A study of the buckling behavior of the clamped shallow spherical cap modelled under various boundary conditions at the pole is included as an addendum.			



## KEY WORDS

## LINK A

## LINK B

## LINK C

ROLE

WT

ROLE

WT

ROLE

WT

SHELLS

SHELLS OF REVOLUTION

STRUCTURAL ANALYSIS

BUCKLING

BUCKLING OF SHELLS

BUCKLING OF IMPERFECT SHELLS

IMPERFECTIONS

IMPERFECT SHELLS













Thesis

139074

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Ryan

c.1

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